[With this Part is circulated, as a Supplement to the current Volume of Transactions, an Appendix to the Makerstoun Magnetical and Meteorological Observations.]

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XXII. PART II.—FOR THE SESSION 1859–1860.

CONTENTS.

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IX.—*Description of the Plant which produces the Ordeal Bean of Calabar*. By John Hutton Balfour, A.M., M.D., F.R.SS. L. & E., Professor of Medicine and Botany in the University of Edinburgh. (With two Plates, XVI. and XVII.)

(Read 16th January 1860.)

It has been long known that in various parts of Africa, the natives are in the habit of subjecting to the ordeal of poison parties who are suspected of crimes. On the east coast, we meet with *Tanghinia venenata*, yielding the Tanghin poison-nut of Madagascar; and on the west coast, seeds and barks of different kinds have been employed as ordeals,—the sources of which, however, have not been hitherto fully ascertained.

Dr Kirk, naturalist to the Livingstone Expedition, states, that the Manganja tribe, in the south-east of Africa, believe in a God, and in medicine, or the ordeal which he directs as the means of discovering crime. If the ordeal causes vomiting, it shows innocence; if it acts by the bowels, crime, and the person is put to death. But the doctors have a good knowledge of which to give, for there are different plants used.

In the district of Old Calabar a bean is used for an ordeal poison, to which the name of Eséré is given. It possesses extraordinary energy, and the attention of the missionaries of the United Presbyterian Church of Scotland in that quarter was directed to this poison several years ago. The Rev. H. M. Waddell, one of these missionaries (now in Edinburgh), brought some of the beans to this country; and of late, numerous specimens of them have been sent or brought to Edinburgh by other missionaries. As they possessed considerable interest in a toxicological point of view, they naturally attracted the attention of medical jurists.

The effects and mode of action of the ordeal bean were examined in 1855 by Dr Christison (*Edinburgh Monthly Journal of Medical Science*, March 1855). The information obtained by him as to its effects on the negroes in Africa from observers there, merely went to show that the bean did not cause any serious injury if it was vomited not long after being taken; but that, if retained, it invariably caused death, sometimes within an hour, and apparently occasioning insensibility and slight convulsions. On careful inquiry, however, he found that the real phenomena, and the kind of action exerted on the body, are quite different.

From an incidental observation made on himself, in consequence of an overdose having been accidentally swallowed, it appears that the ordeal bean causes giddiness, a sense of not unpleasant weariness and heaviness in the limbs, then great languor and tumultuous irregularity of the pulse and heart, extreme weak-

ness and faintness, great abridgment of the power of volition over the voluntary muscles, very slight twitches of the muscles of the chest, but no diminution of sensibility, and no disorder of the mental functions. The articulation becomes sluggish; but it is not imperfect, if the words be pronounced deliberately and with attention. As these effects wear off sleep supervenes, and it lasts for a few hours; after which there is languor of the muscles, and inaptitude for exertion, passing off before next day. The effects now described were the result of taking twelve grains carefully chewed, while the stomach was empty. As the stomach was cleared out by an emetic so soon as the giddiness and weariness of the limbs were felt decidedly, it is not improbable that even that small dose, amounting to a fourth part of one bean, might prove speedily fatal.

The mode of action seemed to be by paralyzing the heart on the one hand, and on the other by suspending the influence of volition over the muscles, but without affecting sensation. This conclusion was confirmed by a few experiments on the lower animals, showing that an emulsion of the seed introduced into the cellular tissue under the skin occasions sudden feebleness, slight muscular twitches, muscular paralysis, and death in a few minutes by arrestment of the heart; which is accordingly found immediately afterwards to be paralysed, and filled in its left cavities with florid blood. Sensibility was manifested so long as advancing paralysis did not take away the power of expression.

Dr Sharpey has since communicated to Dr Christison some experiments made at his request on the frog with an alcoholic extract of the seed. This extract was found by Dr Christison, by experiment on quadrupeds, to concentrate in itself the activity of the seed, and to be consequently a poison of intense energy. Dr Sharpey ascertained by experiments on the frog, that it paralyses the action of the lymph-hearts, does not impair circulation in the vessels, appears to suspend the influence of volition over the muscles, does not affect the direct excitability of the muscular fibre, and apparently also leaves the muscles excitable by stimuli conveyed along the nerves, other than volition, at least by electricity.

Dr Christison attempted to detach the active proximate principle from the alcoholic extract; but the quantity of material was insufficient to enable him to do more than ascertain, that an alkaloidal principle was not separable by some of the simple processes of proximate analysis used in similar circumstances.

The beans are said in Africa to lose their poisonous qualities after being roasted or boiled; but this is extremely doubtful. In the cooked condition, however, they are (according to Mr Waddell) sometimes administered medicinally, without producing poisoning. The difference of apparent effect is often remarkable. Mr Hewan, medical missionary of Calabar, states, that in one case which came under his own notice, a woman who was accused of injuring her child by witchcraft, came in from a distance, strong in innocence, and demanded to have the ordeal administered. She ate twenty-four beans and

did not die. Next day, another woman, encouraged by her escape, underwent the ordeal, and she ate twenty-two beans, and died. There was no vomiting in either case. The difference of effect might be owing either to an actual difference in the beans administered in the two cases, or to their mode of preparation. The fetish-man who administers the poison can manage this beforehand, according as he wishes the party to live or die. The natives themselves do not seem to have much faith in the bean as an ordeal, rather looking upon a summons to undergo the test as a sentence of death, and, if in their power, making their escape and going into exile.

The Rev. ZERUB BAILLIE, another missionary, now in this country, who studied medicine partially at our school, writes to me in the following terms:—"I have several times been called upon to visit people under the influence of this poison. The symptoms, so far as I have observed them, are as follow:—The patient, when fairly under the influence, presents a peculiarly stupid, drunken look, the face is flushed and swollen, the eyes protruding, the mouth externally has somewhat the appearance of a person under salivation. At first there is a considerable flow of saliva, which eventually becomes frothy; the pulse is moderately full; the limbs gradually become powerless; the person walks very like an individual under the influence of strong drink; the muscles of the tongue, as well as the other muscles of the body, soon appear to get into a state of paralysis; the breathing becomes laborious, and the patient gradually sinks. I have used with good effect both the stomach-pump and emetics. I may state, that the bean is generally administered in supposed cases of witchcraft. The accused parties, whether male or female, are tried very much in the same way as witches were dealt with in Scotland, in former times. The judges are the chiefs of the town. Each chief puts down an Eséré on the ground, and the accused party takes them up one by one, chews, and swallows them. Sometimes as many as twenty or thirty are thus taken. If he vomits, he is innocent; if he dies, guilty. On questioning my boy from Calabar, he tells me that in cases where they wish the accused party to die, they rub the Eséré over with the gall of the leopard before administering it."

It is a common custom in Old Calabar to sacrifice human lives on the death of a king. In 1847, when King Eyamba died, the horrid practice was carried on. The ordeal of poison by the Eséré bean, commonly called "chop nut," was also, as usual, put in execution to discover who, by the *ifod* or native witchcraft, had killed the deceased man. It was thus employed as a judicial proceeding for the detection of crime, according to native ideas; and although the missionaries tried then, and at other times, to enlighten the minds of the natives on the subject, and had enlisted the succeeding King Eyo in their views, still the chiefs generally, could not be persuaded to abandon the use of the Eséré. The following account is given in a missionary journal:—"In the early part of 1852, Archibong, Duke

of Duke Town, died. His mother, a great lady, and highly connected and influential, sought to comfort herself for the death of her son by the death of as many as she could lay hands on. Four distant connections of his were charged by her before a high official, brother of the late King Eyamba, and they had to purge themselves by the poison ordeal from the imputation of having caused his death by witchcraft. They all died. Some of his wives were also put to death that day in the same way. The next day, a host of armed slaves came from the Qua-river plantations, and filled the town, determined, they said, to find out who had killed Archibong. Supported by these, the bloody-minded woman had many more put to death, charging them with practising witchcraft against her son, and making them chop nut. The process was publicly carried on in the open town-place, and in presence of the chief men. The efforts of the missionaries to arrest the work of destruction were in vain. Duke Efraim, who was next in authority to the deceased, was full of wrath that they should presume to interfere by a single word in the matter, and the murders went on, till above twenty free people were known to have died by the poison ordeal."

The beans which Mr Waddell brought to Scotland germinated in the Botanic Garden, as well as in Professor Syme's garden at Milbank; but although the plants grew vigorously, and produced twining stems and leaves, they never flowered. The twigs and foliage were quite identical with native specimens which I have lately received from Africa. Some of our plants were much injured by the red spider. Attempts were made by the missionaries to get native specimens of the flowering stems of the plant, but they were for a long time unsuccessful; at length, however, the Rev. W. C. Thomson succeeded. Writing to Mr Andrew Murray from Ikoneto, Old Calabar, on 29th August 1859, Mr Thomson says—"I am happy to be at length able to send you samples of the flower of the Eséré or ordeal bean. You may perhaps wonder why none have been sent home long ere this; the explanation being not so much remissness on our part, as rather fortunate ignorance on that of the natives. Very few of them (none that I have ever met with) know anything of the plant at all, however well acquainted they may all be with the actual bean. Among the first things I did on returning from Britain last year was to offer a reward to be shown a veritable living plant. Many tried for the reward. Various most different leaves were brought to me as those of the Eséré; nor was it till the ripe fruit was seen that success was obtained, and a fine plant pointed out to me, with numerous pods still attached. From this plant we have since got the flowers also. For want of spirits, I have had to preserve those I am sending in a solution of common salt, which I trust will keep them in an examinable condition; otherwise, I must trust to your seeing those Mr Baillie is taking with him from the same source, but preserved in spirits."

Unfortunately, the specimens sent by Mr Thomson have not reached Mr Murray, but those brought by my friend and former pupil Mr Baillie have been

given to me for examination. By means of them, I have been able to make out fully the characters of the plant. After doing so, I was favoured with the use of a letter from Mr THOMSON to Mr MURRAY, in which he gives the characters he had noticed in the living plant. These are remarkably well detailed, and point out Mr THOMSON as a very good botanical observer, and one who is likely to add to our information relative to the Flora of Africa. It is pleasing to observe that all the missionaries at Old Calabar have a taste for natural science. They have already contributed many valuable zoological and botanical species. May they long be spared to carry on their noble evangelizing efforts and their natural history pursuits.

The ordeal bean has been found to belong to the natural order *Leguminosæ*, the sub-order *Papilionaceæ*, and the tribe *Phaseoleæ*, and it appears to constitute a new and distinct genus. It is curious to find, that among the papilionaceous plants, which yield our edible beans, peas, and pulse of various kinds, there should occur many poisonous genera and species. Among them may be noticed *Coronilla varia;* the seeds and bark of *Laburnum;* seeds of *Lathyrus Cicera*, and of *Lathyrus Aphaca,;* the root of *Phaseolus multiflorus*, or the scarlet runner, and of *Phaseolus radiatus*; the bark of the root of *Piscidia erythrina*, or Jamaica dogwood; the branches and leaves of *Tephrosia toxicaria* (the two latter plants being employed as fish-poisons); *Gompholobium uncinatum*, which is said to have poisoned sheep in the Swan River Colony; and the plant now under consideration. The Calabar bean-plant seems to be closely allied to *Phaseolus*, and it has also many characters in common with *Vigna*, *Dolichos*, and *Lablab*, all of which genera belong to the tribe *Euphaseoleæ* of BENTHAM. The legumes which were given to me by Mr BAILLIE and by Mr HEWAN have an apparent resemblance to those of *Mucuna*. This induced Mr MURRAY, in a communication to the Botanical Society, to refer the plant to this genus, under the name of *Mucuna venenosum*. Mr MURRAY was confirmed in his opinion by the character of the seeds. He had not seen the flowers.

The character by which the plant seems to be specially characterised is the stigma, which has a remarkable crescentic or hooded appendage (Plate XVI., figs. 6 and 7). On this account I have proposed to call the genus *Physostigma*, from φυσάειν, to inflate, and στιγμα, applied to the upper part of the style. It will be placed close to *Phaseolus*, from which it differs in the stigma, and in the long grooved hilum of the seed. In the last character it approaches *Mucuna*. The spirally twisted carina and style of *Phaseolus* does not occur in *Physostigma*. To the species I have given the name of *venenosum*, in allusion to its poisonous qualities. I transmitted specimens of the flower to my friend and former pupil Dr THOMAS ANDERSON, of her Majesty's Indian Service, who is now engaged in examining the Indian *Acanthaceæ* in the Hookerian Herbarium at Kew. He kindly examined the specimens, and compared them with the allied plants in the herbarium. He informs

me,—"I have dissected the flower, and compared it with numerous drawings and descriptions of *Phaseolus* and *Lablab*, both of which genera I knew well in India. The flowers of your plant are, as you remark, quite phaseoloid; but then the seed is different from any known seed of that genus. The seed, with its elongated sulcated hilum, is very close to that of *Mucuna*, but the characters of the flower and pod remove it from that genus. Were the carina and pistil not so completely *Phaseolus*, it would otherwise, and especially in its nodose inflorescence, come near to *Lablab*. As it is, I cannot see how one can help making a new genus of it."

The flowers were subsequently shown by Dr ANDERSON to Mr BENTHAM, who is the chief authority in regard to *Leguminosæ;* and in a subsequent letter Dr ANDERSON says:—"Mr BENTHAM desires me to tell you that the plant is very near *Canavalia* in the long hilum and the calyx, and very near *Phaseolus* in the flower generally, except in the stigma." The following is the description of the genus. The characters are illustrated by excellent drawings (Plates XVI. and XVII.), made, with his usual botanical accuracy, by Dr GREVILLE, from specimens and careful dissections supplied by me:—

Nat. order, *Leguminosæ;* Sub-order, *Papilionaceæ;* Tribe, *Euphaseoleæ.*

PHYSOSTIGMA VENENOSUM; Ordeal Bean of Calabar.

GEN. CHAR.—Calyx campanulatus, apice quadrifidus, laciniis brevibus, lacinia suprema bifida. Corolla crescentiformis, papilionacea; vexillum recurvum, apice bilobatum, basi angustatum, margine utroque auriculatum, membranâ inflexâ auctum, medio longitudinaliter bicallosum; alæ obovato-oblongæ, liberæ, supra carinam conniventes, versus basin appendiculatæ, curvæ; carina vexillum æquans, apice rostratum, rostro multum incurvo. Stamina decem, diadelpha, filamento vexillari libero, supra basin appendiculato. Discus vaginifer. Ovarium stipitatum, 2–3-ovulatum. Stylus cum carina tortus, infra stigma subtus barbatus; stigma obtusum, cucullo cavo oblique tectum. Legumen dehiscens, oligospermum, elliptico-oblongum, subcompressum, extus rugosum, endocarpium intus telâ laxâ cellulari tectum, isthmis cellulosis inter semina. Semina strophiolata, hemisphærico-oblonga hilo late-sulcato semicincta.

Herbæ suffruticosæ volubiles in Africa occidentali tropica crescentes: foliis pinnatim-trifoliolatis, stipellatis, floribus nodoso-racemosis, purpureis.

P. venenosum.—The only species of the genus as yet known.

A large twining plant, turning from right to left.

Root spreading, with numerous fibrils, often having small succulent white tubers attached. *Stem* about two inches in diameter at its thickest part, sometimes attaining a length of fifty feet, cylindrical, of a brown-gray colour, roughish; younger branches of a dark-green colour, thickened at the nodes; branches twisting on themselves and round those in their vicinity; wood of the stem very porous, giving out, when cut, a pretty free stream of limpid fluid, which is

slightly astringent and acrid; woody bundles arranged in wedges; bark giving out a reddish, gummy exudation, which becomes very dark on drying.* *Leaves* alternate, petiolate, stipulate, pinnately-trifoliate; leaflets ovate, acuminate, each having a struma, which serves as a short petiolule, and two small, thickened, acute, and somewhat falcate stipels; lateral leaflets oblique at the base. *Venation* reticulated, curved-veined, with a prominent midrib and two less distinct lateral ribs. *Petioles* about three inches in length, rounded on the lower side, grooved on the upper, having a pulvinus, with two minute triangular stipules, which are reflexed at the margins. *Inflorescence* axillary on pendulous multifloral racemes; rachis of raceme zigzag and knotty; knots rounded, irregular on the surface like minute tubers, bearing the pedicellate flowers. *Pedicels* about a quarter of an inch in length, two or three arising from the same nodosity, from which they separate by disarticulation; flowers articulated to the pedicels; at the upper part of the pedicel, close to the flower, are two callosities representing bractlets, and sometimes a sort of thickened ring. Flowers about an inch in length, half an inch across. *Calyx* campanulate, four-cleft at its apex, the upper division being notched, and its segments ciliated; the calyx is thus composed of five united sepals, and it assumes a somewhat bilabiate appearance. *Corolla* papilionaceous, beautifully veined, of a pale pink colour, with a purplish tinge (THOMSON), when preserved in spirits assuming a pale yellowish hue, curved in a crescentic manner. *Vexillum* external, large, completely covering the other parts of the flower in æstivation; bilobate at the apex, which is completely recurved, narrowed at the base, with two small projections on each side of the very short claw which is furrowed, and has two longitudinal callosities in the middle; basal portion of limb of vexillum having rounded lobes, which are turned inwards so as nearly to meet. *Alæ* large, more deeply coloured than the other parts of the flower, reaching to the edges of the vexillum in bud, obovato-oblong, curved, narrowed into a curved hook-like claw, with a projection above it, edges slightly incurved. *Carina* as broad as the alæ, and much longer than them, equal in length to the vexillum, broad below, prolonged upwards into a narrow sort of rostrum, which ends in a blunt apex, and is curved upwards and backwards, so as to form between two-thirds and three-fourths of a circle; petals of keel ovate-oblong, with triangular acuminate processes projecting from above their base on the inside, and with very narrow claws. *Stamens* ten, diadelphous, nine united by their filaments for about two-thirds of their length, vexillary free stamen an inch and a quarter long, with an appendage to the filament immediately above its base; staminal sheath swollen below, filaments long, not thickening upwards; anthers two-lobed, dehiscing longitudinally. *Disk* at the base of the ovary thickened, with a sheath extending upwards over the gynophore. *Pistil* more than one and

* For an account of the stem, wood, and bark, I am indebted to notes furnished by the Rev. W. C. THOMSON of Old Calabar.

a half inch long; ovary stipitate, rough on the surface, not hairy; style curved, smooth except below the stigma, where the concavity is covered with a continuous line of hairs, which give a marked barbate appearance; stigma blunt, covered by a remarkable ventricular sac or hood, which extends along the upper part of the convexity of the style.* *Ovules* two or three attached to the ventral suture by a broad process, crescentic in form, with a convex placental edge, and a long hilum. *Legume* in the young state green, and somewhat falciform, afterwards becoming dark-brown and straight; sutures slightly prominent, ventral one grooved, interior lined with white loose pith-like cellular tissue, in which the ovules are embedded, and by which they are separated from each other. Full grown legume about seven inches in length, elliptico-oblong, with an apicilar curved point, stipitate (stalk about an inch in length), dehiscent, outer integument (epicarp) separating from the inner, dark-brown, rugose, marked with anastomosing fibres, which run partly in a transverse direction, and partly along the edge of the pods. Inner covering (endocarp) of legume pale-coloured and roughish externally; ventral suture furrowed. *Seeds*, two or three, about an inch long, three quarters of an inch broad, each weighing from 40 to 50 grains, separated from each other by a woolly cellular substance; hilum dark, sulcate, with brown elevations on either side, extending along the whole convex placental edge of the seed; other edge nearly straight; cotyledons pale, hypogeal.

* Mr Thomson, in a letter to Mr Murray, describes this process in the recent flower as "resembling an admiral's hat set in a jaunty manner."

DESCRIPTION OF THE PLATES.

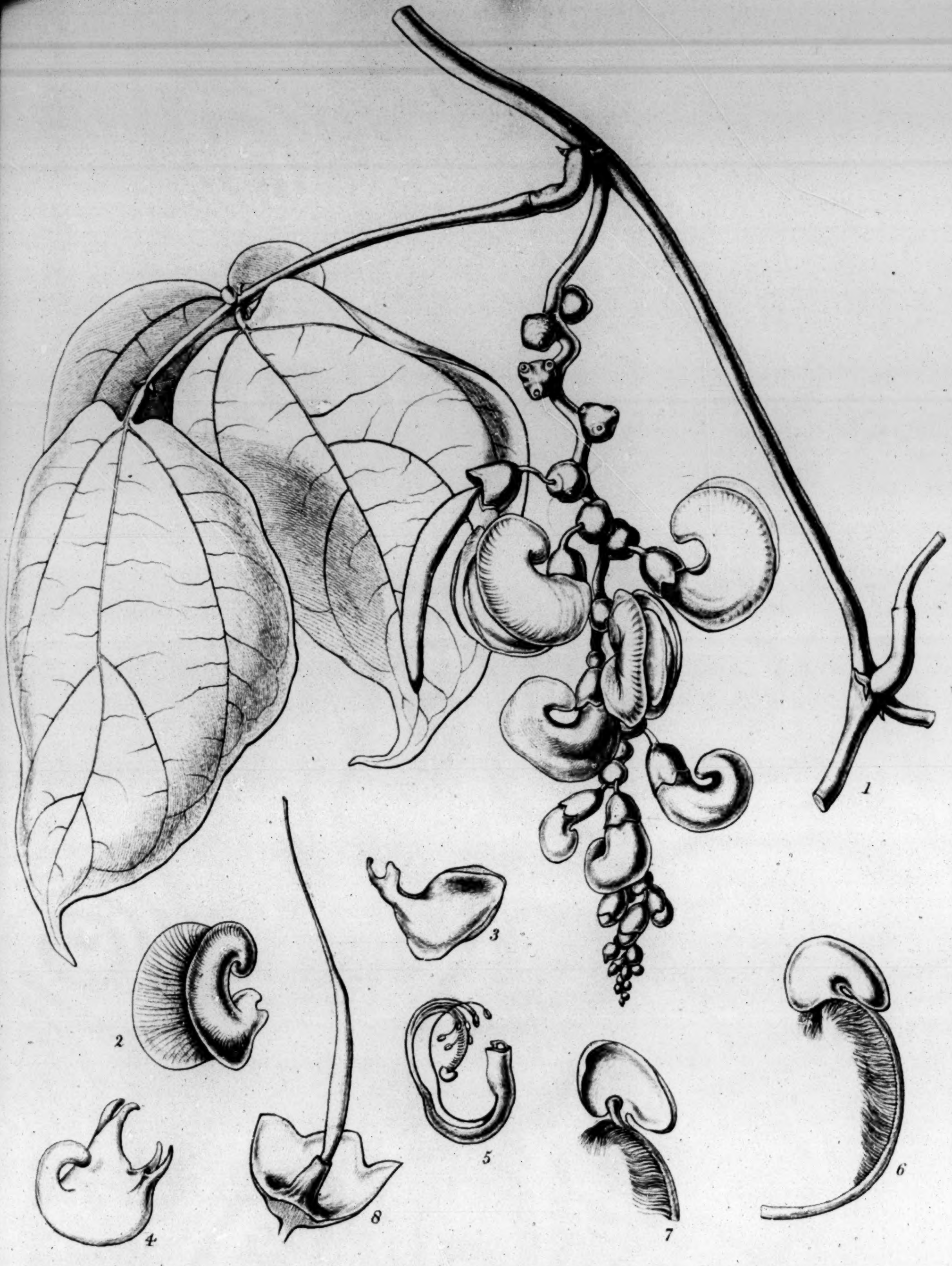
Plate XVI.

Physostigma venenosum, Calabar Ordeal Bean.

Fig. 1. Branch with pinnately-trifoliolate leaves, and nodoso-racemose infloresence, showing also entire flowers with persistent calyx and young legume. Fig. 2. Vexillum separated. Fig. 3. Alæ. Fig. 4. Carina. Fig. 5. Diadelphous stamens. Fig. 6. Upper part of style, bearded, and with cucullate stigma. Fig. 7. Upper part of bearded style, with stigmatic hood laid open. Fig. 8. Calyx and young legume. Figs. 6, 7, 8, magnified.

Plate XVII.

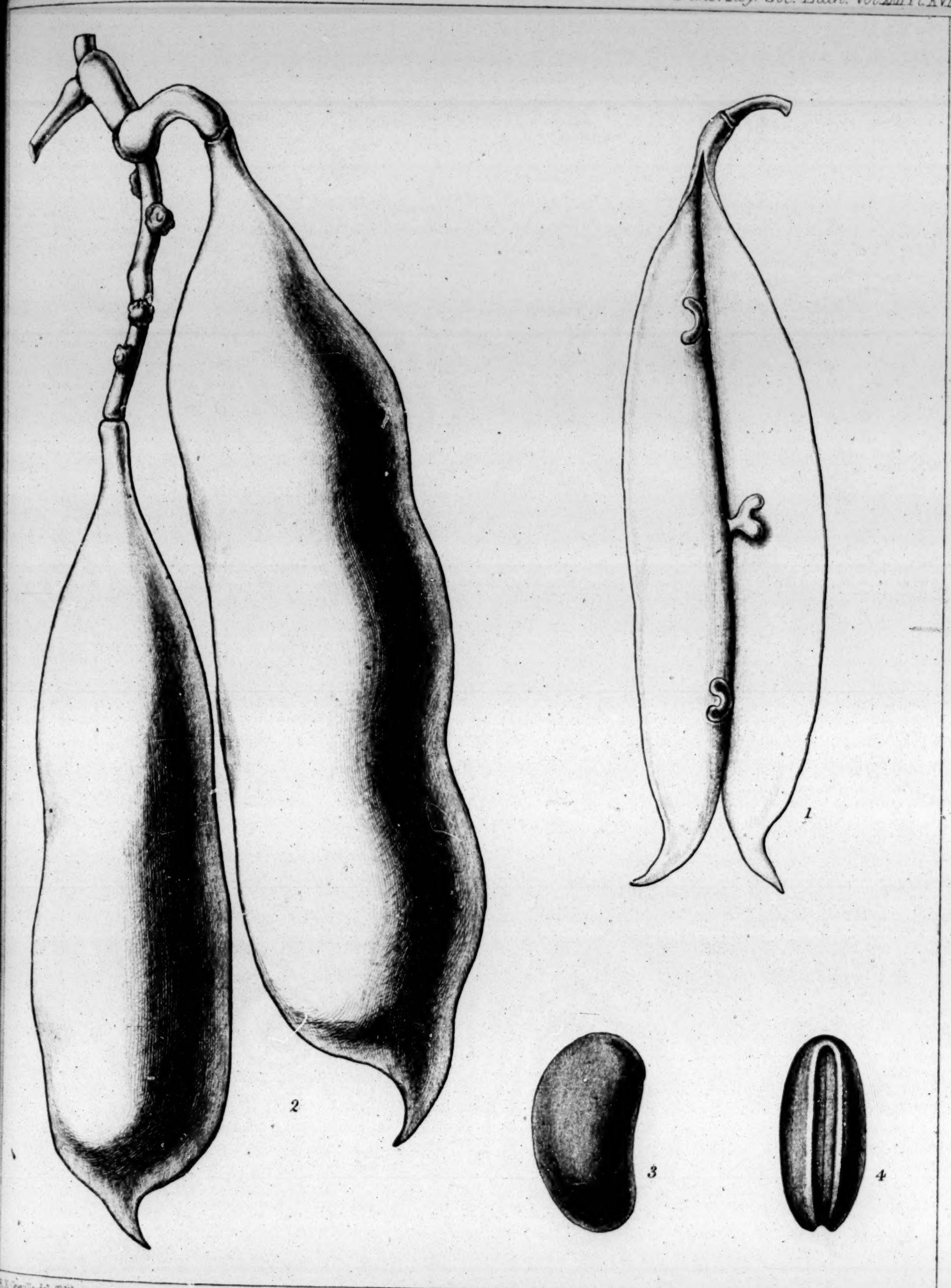
Fig. 1. Young legume of *Physostigma venenosum*, with three ovules. Fig. 2. Full grown legumes of ditto. Fig. 3. Seed of Ordeal Bean seen laterally. Fig. 4. The same, showing the sulcate and extended hilum on the convex edge. All the figures natural size.



R.K. Greville, del. T. West, sculp. W. West, imp.

PHYSOSTIGMA VENENOSUM. Calabar Ordeal Bean.

Fig: 1. Branch with pinnately trifoliolate leaves & nodoso-racemose inflorescence; showing also entire flowers, persistent calyx & young pod. Fig: 2. Vexillum separated. Fig: 3. Ala. Fig: 4. Carina. Fig: 5. Diadelphous stamens. Fig: 6. Upper part of style bearded, & with cucullate stigma. Fig: 7. Upper part of bearded style, with stigmatic hood laid open. Fig: 8. Calyx & young legume. Figs 6.7 & 8. magnified.



R. K. Greville del. T. West, sculp.

W. West, imp.

Fig: 1. Young pod of Physostigma venenosum, with three ovules. Fig: 2. Full grown pods of Do. Fig: 3. Seed or Ordeal Bean seen laterally. Fig: 4. The same showing the sulcate and extended hilum on the convex edge. All the figures natural size.

X.—*On an Unusual Drought in the Lake District in* 1859. By JOHN DAVY, M.D., F.R.S. Lond. & Edin., &c.

(Read 17th April 1860.)

In a former communication to the Royal Society of Edinburgh, I gave an account of an unusual fall of rain in the Lake District in the month of January last year. That occurrence was followed by its opposite in May, June, and July; not for a long period, not since 1826, has the district suffered more from want of water than in those months.

This drought is best shown by the following table, in which will be found the rain-fall for the several months of the year at five different places, only a few miles remote from each other. The table will also show the remarkable contrast as to excess and deficiency of rain during the period. It may be premised, that at Ambleside, where the drought appears to have been felt as much as anywhere, the ordinary fall of rain for the months in question is about three times as great; thus for May (our driest month of the twelve), taking the average of the preceding eleven years, it is 2·37 inches, for June 4·22 inches, for July 5·27 inches, making a total of 12·36 inches, against 4·54 inches of the months of drought.

TABLE I.

Months.	Kendal.		Lesketh How, Ambleside.		Keswick.		High Close, above Grasmere.		Seathwaite, Borrowdale.
	Inches.	Rainy Days.	Inches.	Rainy Days.	Inches.	Rainy Days.	Inches.	Rainy Days.	Inches.
January, . .	6·514	17	14·82	19	11·168	21	10·95	19	23·40
February, .	4·022	18	7·29	22	5·214	20	6·29	21	15·80
March, . .	5·617	20	10·32	23	9·512	21	8·78	23	20·84
April, . .	3·900	12	5·44	12	4·868	13	5·27	16	12·71
May, . . .	0·123	1	0·55	4	0·206	2	0·23	5	1·04
June, . . .	2·024	12	1·91	13	2·446	9	2·81	14	5·95
July, . . .	1·757	8	2·08	10	2·866	7	2·55	9	3·33
August, . .	5·224	10	5·45	12	5·467	12	6·55	15	13·38
September, .	7·343	21	11·36	20	9·346	20	11·16	22	15·32
October, . .	2·760	12	6·89	14	3·834	10	4·99	14	8·27
November, .	5·075	17	10·08	16	6·595	13	8·61	17	13·55
December, .	3·931	13	7·93	16	5·451	15	6·59	16	13·70
	43·290	161	84·12	181	66·883	163	75·08	191	147·29

For the Table which follows I am indebted to Mr SAMUEL MARSHALL of Kendal, a gentleman of whose accuracy as an observer I have before made mention. The results it contains, expressive of the meteorological qualities of most importance, are applicable, with certain allowances, to the Lake District generally, and more especially as regards atmospheric temperature, and the prevailing winds.

TABLE II.

Months.	Barometer.			Thermometer.			Thermometer on Grass.		Mason's Hygrometer.		Quantity of Rain in Inches.	Number of Rainy Days.	Prevalent Winds.	Ozone.
	Maximum.	Minimum.	Mean.	Max.	Min.	Mean.	Solar Radⁿ.	Terrest. Radⁿ.	Dry Bulb.	Wet Bulb.				
January, . .	30·398	29·097	29·853	52°	28°	40·468	46·6	33·7	40·4	39·1	6·514	17	S.W.	1·7
February, .	30·483	29·048	29·712	52	27½	40·946	53·7	34·3	40·5	39	4·022	18	S.W.	4·1
March, . .	30·201	28·894	29·701	59½	24	44·113	63·1	39·5	43·7	41·8	5·617	20	S.W.	4·3
April, . .	30·085	29·454	29·694	68½	24	43·416	82·3	34·6	45·6	41·3	3·900	12	S.W.	4·2
May, . . .	30·251	29·660	29·922	79	29	54·532	10·4	35	60	54	0·123	1	N.E.	3·4
June, . . .	30·099	29·578	29·854	80	39	59·216	97·3	46·8	62·3	56·3	2·024	12	N.E.	3·2
July, . . .	30·265	29·739	30·021	86	41	63·468	104·4	49·8	66·2	60·1	1·757	8	S.W.	2·5
August, . .	30·258	29·219	29·837	83	39	61·089	93·4	47·8	62·7	58·1	5·224	10	S.W.	2·4
September, .	30·139	29·279	29·677	66	35	53·733	83·6	42·4	54·4	52·1	7·343	21	S.W.	3·0
October, . .	29·965	28·936	29·566	71	19	48·113	69·3	39·8	47·6	45·8	2·760	12	N.E.	2·0
November. .	30·566	28·502	29·769	53½	22	39·541	52·3	30·1	37·4	36·1	5·075	17	N.E.	2·1
December, .	30·459	28·756	29·552	54	11	33·008	31·3	30·5	38·4	23·6	3·931	13	S.E.	3·2
Annual Means, &c.	30·264	29·180	29·763	67	28	48·470	73·4	38·7	49·9	45·6	48·290	161	S.W.	3·0

The following Table (No. III.) is given for the purpose of showing the great inequality of the fall of rain in different parts of the United Kingdom. For the observations from which it is framed, I am chiefly indebted to correspondents.

Comparing these Tables, it would appear, that whilst one portion of the country was suffering from deficiency of rain, other parts of it had rain in excess, and both in a remarkable degree; for instance, London and the Lake District. It would appear, also, that over the country generally, even where for three months a drought prevailed, the yearly fall of rain exceeded the average. At Seathwaite, in the upper part of Borrowdale, according to the observer there, Mr JOHN DIXON, the excess, in that spot, so remarkable for its rain, exceeded that of the average of the last fourteen years by 17 inches.

Recurring to the drought as experienced in the Lake District,—a district, from the nature of its declivities and the quality of its soil, peculiarly apt to suffer

TABLE III.

Months.	Penzance.	Burcher, near Kington, Herefordshire.	London.	Cambridge.	Wakefield.	Caton about four miles east of Lancaster.		Arncliff, head of Wharfdale.	Edinburgh.	Glasgow.	Stornoway Castle, Isle of Lewis.
						Caton Farm,	near Normanton, Yorkshire.				
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
January, . .	3·18	1·16	0·794	0·310*	0·709	0·72	4·095	8·76	1·86	5·300	5·43
February, . .	2 ·3	1·51	1·232	1·117	1·460	1·48	2·751	5·91	1·19	5·327	3·61
March, . . .	2·74	2·38	1·331	1·259	2·485	2·36	4·709	11·06	2·54	5·160	6·16
April, . . .	3·10	2·47	2·528	1·379	3·766	4·35	3·208	5·30	2·78	4·437	3·12
May, . . .	1·04	1·12	2·214	1·284	0·784	0 37	0·222	0·34	0·17	0·582	0·55
June, . . .	0·59	3·65	2·896	1·243	3·345	3·47	1·764	4·24	2·04	1·953	2·21
July, . . .	1·00	2·61	2·929	2·305	5·558	3·25	1·854	3·55	3·08	2·538	3·46
August, . . .	3·40	3·53	2·652	1·638	3·957	4·20	3·742	4·66	0·67	2·858	3·46
September, . .	4·42	3·98	4·039	2·103	3·434	3·88	5·558	9·97	1·35	4·867	4·76
October, . . .	5·34	3·73	2·496	3·746*	2·777	3·19	2·603	5·36	3·04	6·062	2·64
November, . .	3·62	4·33	2·930	0·864	2·053	3·02	3·494	9·17	2 48	3·243	3·08
December, . .	8·28	4·49	2·248	0·070	2·879	2·71	4·332	5·98	1·44	2·415	4·06
	39·01	34·96	28·289	17·818*	33·207	33·50	38·330	74·30	22·64	44·742	42·53

* It is stated that the rain-gauge was out of order during part of January and part of November, and that, to make up the deficiency, about 5 inches, it is estimated, should be added, making a total of about 23 inches for the year.

from any deficiency of rain,—its effects were witnessed not only in a failure of most of the springs and a want of water distressingly felt by the inhabitants, but also on vegetation; those plants requiring moisture, suffering; those benefited by warmth and dryness—the comparative few—flourishing. The crop of small fruits, such as the gooseberry, currant, strawberry, was unusually scanty and poor; that of mushrooms, and of other fungi,* was unusually abundant. The same in regard to flowers; the lavender flowered in fine profusion; roses the contrary, and with a very small growth of wood. The drought took effect severely on the grasses; the hay-grass, the great crop of this pastoral district, was only about one-third an average one. Animals, I need hardly remark, were not exempt from its influence; some insects were unusually abundant and troublesome; others the opposite. During the dry months, our valley was almost deserted by the swallows.

* The common mushroom, *Agaricus campestris*, was so abundant, that in the Lancaster market it was sold at a penny a quart, about four or five times cheaper than usual: it was met with, too, in places where, it is said, it had never before been found. Of wild flowering plants, the common harebell, *Campanula rotundifolia*, was unusually plentiful, and in many spots where I had never seen it before.

The weather which followed this drought was also abnormal. Snow accompanied with frost fell in October;* and this before many of the trees had acquired their autumnal tints. Moreover, the winter months, up indeed to the present time, have been remarkable for uncommon vicissitudes of temperature, for frequent snow-storms—the snow lying much longer than ordinary—and for severe gales, some of these almost hurricanes, accompanied with sudden and great fluctuations of the barometer.

LESKETH HOW, AMBLESIDE, *March* 22, 1860.

Postscript.

The loss of stock amongst the farmers in the Lake District, the consequence of the drought and the inclement winter which followed it up to the present time has been great, and it has continued increasing. In the *Kendal Mercury* of the 7th April there is an account of it, so descriptive, and, as I believe, truthful, that I am induced to transcribe it. It is headed, "Dreadful mortality amongst the mountain sheep in Westmoreland." "In our last week's impression" (it proceeds), "we noticed the snow-storm that fell on the hills and valleys in Westmoreland, on Saturday morning the 25th ult., and that a vast number of sheep, not only on the hills, but on the low grounds, were buried beneath the snow, and that in consequence of a large quantity of rain falling along and at intervals during the storm, the worst fears were entertained for the

* Mr SAMUEL MARSHALL, in his summary of Meteorological observations for this month, remarks, "On the morning of the 21st October we had the first frost this season, and on the following one the first snow, and the next a heavier fall still. The thermometer has not been below the freezing point since the 9th May till the 21st October, or more than five months." A very unusual degree of cold, about the same time, was observed elsewhere. Mr LOWE in a note of the 23d of October, from Highfield House Observatory, headed "Great Cold," published in the *Evening Mail*, says, "It is scarcely three weeks since I had to announce a degree of heat greater than had been known to have occurred in October (viz., 77°·5), and now the same has to be said with regard to the intense cold of the past two nights. Yesterday the *minimum* temperature was 23°·5, and this morning it fell to 22°·4; previously 24°·6 was the greatest cold that had been registered here." It was curious to observe the aspect of plants at this time;—the foliage of many trees, such as the sycamore and the ash, their leaves still green, were shrivelled and curled by the frost, so that their under surface was conspicuous, whilst the roses, the China variety still in flower, were weighed down by snow. The effect of the severity of the winter as to cold was not less strongly marked on vegetation than the summer drought; some of the hardier plants were killed, for instance the Russian violet, which during the preceding winter had flowered uninterruptedly; and yet, even the shallower lakes, such as Rydal Mere, were frozen over, so as to allow of skating, only for two or three days, and this only once, so rapid were the changes of temperature from a low degree, as 12° to 15° and 20° to 34°–40°; it was rarely higher. And, as the mildness of last winter was shown by a forward vegetation, so the severity of the last and the protracted low temperature have been indicated by the opposite this year; now, on the 21st of March, the flower-buds of the *Ribes sanguineum* have only just begun to unfold, and not a leaf-bud of the sweetbrier has yet opened.

safety of the sheep; and we are sorry to say that those fears have been realised to an alarming extent. The snow was nearly all washed from the grounds by the rains which fell during the succeeding week, and then the shepherds began to have some idea of the destruction amongst their flocks, and it was truly fearful. On Saturday last, one skinner in Kendal received no less than 250 skins from the neighbourhood of Shap, and other skinners in this town had an almost fabulous number. Cartloads of skins were also forwarded on Saturday to Penrith, and other towns and villages in the neighbourhood of the hills; and they still, nearly daily, keep arriving here from the fells. On Wednesday last, 100 skins arrived from one farm, and it was some time before the owner could dispose of them, as the skinners had so large a number still unpulled that were rotting and becoming putrid in their skinneries. The sheep, whose skins are now brought in, have not all perished in the snow-storm, but they were so weak and emaciated from the long winter, and hunger, and cold, that they reeled about, and then tottered, fell, and died by scores together. It is said that one-half of the sheep in the parish of Bampton have perished, and that Mr T. Mounsey, in that parish, has lost 500, and Mr T. Abbott, of Thornthwaite Hall, near Shap, counts up his loss to more than 1200 head. Indeed, the loss has been fearful all along the Lake Mountains, and the range of hills extending from Coniston Old Man to Stainmore. From Coniston, Hawkshead, Ambleside, Troutbeck, Kentmere, Longsleddale, Selside, Shap, Bampton, Crosby, Ravensworth, Ravenstonedale, Kirby Stephen, Garsdale, Hawes, Wensleydale, and Dent, the loss has been great, and the flocks are very weak and sickly, and large numbers are daily dying. Never, in the memory of the oldest shepherd on the hills of Westmoreland, can be remembered so fearful a mortality amongst the mountain sheep, and great fears are entertained that it has not yet reached its highest pitch." These fears, I regret to add, are too likely to be realised; on this 9th of April there has been another fall of snow, succeeding a fall of rain of 1·15 inch in the twenty-four hours; this morning, not only were the hills covered with snow, but even the lower dales. Since April last year, that month included, I find recorded here thirteen falls of snow, in some instances mixed with sleet and rain, the whole equal to, that is, yielding when thawed, 6·9 inches of water. Now, supposing it to have been all snow, as it probably was on the higher fells, the total depth of snow there, if accumulated, would be little short of 83 inches.* It is remarkable that from the 23d of October, when snow first fell, up to the present time, some of the higher hills have not been free from snow.

Incidents, catastrophes, such as have been described above, in connection with

* Of course, according to the quality of the snow, the proportion of water it will yield when thawed must vary; in one instance, when the depth of snow was 6·5 inches, the water from it measured ·54 inch; in another instance, when its depth was 4·5 inches, the water it yielded was ·47 inch. The snow was collected in the funnel of the rain-gauge; its depth was tried where it had not drifted.

adverse seasons, and resulting in scarcity of food and an excessive mortality, seem specially deserving of attention, being equally applicable to the human race—*e.g.*, our army in the Crimea, during the first winter, under the same circumstances—and to brute animals, and may help to account for the extinction of races or species.

Lesketh How, Ambleside, *April* 9, 1860.

XI.—*Upon the Thyroid Glands in the Cetacea, with Observations on the Relations of the Thymus to the Thyroid in these and certain other Mammals.* By WILLIAM TURNER, M.B. (Lond.), Senior Demonstrator of Anatomy, University of Edinburgh.

(Read 2d April 1860.)

In the writings of comparative anatomists, considerable difference of opinion is expressed respecting the position and relations of the thyroid gland in the Cetacea, and some authorities even have asserted that it does not exist in these Mammalia.

JOHN HUNTER states* that he has examined several porpoises, balænæ, and other cetacea, yet "could not observe anything like a thyroid gland."

MECKEL† believed that he found, in a fœtal porpoise (*D. phocæna*), eight inches long, a thyroid gland. He describes it as half an inch broad, two lines thick and high, and of equal depth and thickness both on the middle and sides of the air-tube, in the same position as that in which the gland is found in other mammals. From this examination, however, of so young a fœtus, he does not feel disposed to affirm that, contrary to the opinion of HUNTER, it exists in full grown cetacea. In a subsequent paper‡ he mentions incidentally, that in the dolphins the gland is formed of two quite separate lobes. CUVIER§ states that he has found the gland very distinct in many dolphins and porpoises. In these animals it was divided into two parts, and suspended from the trachea opposite the upper border of the sternum, and some distance from the larynx. CARUS‖ describes the gland in the dolphin and porpoise as consisting of two parts, entirely separate from each other. It is difficult to say, however, from the text, whether he is giving the result of his own observations, or simply adopting those of CUVIER. Dr MARTYN¶ repeats the statement that the cetacea do not possess a thyroid, and he ascribes the supposed absence of the voice in these animals to the want of this glandular structure.

As I have had, during the last three years, opportunities of dissecting three porpoises, and as I have found in them appearances differing from those which I have quoted from the above authorities, I am induced to offer the following description of my observations. The animals were specimens of the common

* On the Structure and Economy of Whales. Philosophical Transactions, 1787.

† Abhandlungen aus der Menschlichen und Vergleichenden Anatomie und Physiologie. Halle, 1806.

‡ Beyträge zur Vergleichenden Anatomie, 1811.

§ Anatomie Comparée, vol. viii.

‖ Traité Elementaire d'Anatomie Comparée, vol. ii.

¶ Proceedings of the Royal Society of London, 1857.

porpoise (*Phocœna communis*), one was a fœtus, twelve inches long; another was a well-grown male, three feet ten inches long; the third being a full grown male, between five and six feet in length.

On removing in each of these animals the large sterno-hyoid and smaller sterno-thyroid muscles, a distinct and well-defined glandular mass was seen lying on the anterior and lateral surfaces of the trachea at its upper end, and extending slightly upwards on each side over the outer surface of the cricoid cartilage. Its position thus closely corresponded with that of the thyroid gland in other mammalia. Instead, however, of being divided into two distinct lateral lobes, as described by CUVIER and CARUS, the gland consisted of a single uniform mass, which in the adult animal was two inches long, extending across the middle line, and closely fitting both to the front and sides of the trachea. The median portion of the gland can hardly be described as an intervening isthmus, for in its supero-inferior diameter it equalled that of the lateral portion. This, in the adult animal, was three-fourths of an inch, in the fœtus, one-fourth.

In the full grown specimen (which was examined in the fresh state, the other specimens having been for some time in spirits), the gland presented a dark purple tint, and a soft and somewhat succulent aspect. At the upper end of each lateral portion, but separated from it by a slight interval, a glandular mass about the size of a small nut was found, apparently an accessory thyroid. In this respect the gland corresponded in its arrangement to one which is occasionally found in the human subject.

In the smaller adult porpoise, in the interval between the two crico-thyroid muscles, and almost concealed by the plates of the cricoid cartilage, a small glandular mass was situated. It had the same colour as the thyroid; but presented more evident indications of being divided into distinct lobes. It was in contact by its deep surface with the crico-thyroid membrane. It must, I think, be regarded as an isolated portion of the thymus.

In the fœtal porpoise, a long and slender glandular process extended from the inferior margin of the median part of the thyroid, downwards along the anterior surface of the trachea, and behind the heart and pericardium, into the posterior mediastinum. This must also be looked upon as a part of the thymus.

Both in the fœtal and smaller adult porpoise, the thymus gland was exceedingly well developed. As the thymus closely corresponds in its structure to the thyroid, and as the relations of the two glands are extremely interesting in a developmental point of view, I purpose, in the next place, describing the general disposition and arrangement of the thymus in these animals.

This gland was exposed by cutting through the sterno-hyoid and thyroid muscles, and by turning on one side the upper end of the sternum. It was composed of two large lateral lobes, separated from each other by a thin layer of cellular tissue. These lobes, of a conical form, were situated for the most part behind the first

bone of the sternum, and immediately in front of the upper end of the pericardium. Their apices projected above the sternum into the lower part of the neck, lying in front of the trachea, and extending upwards almost as far as the lower margin of the median portion of the thyroid gland, from which they were separated by the innominate vein. From each of these lobes a long process of

Fig. 1.

The Thyroid and Thymus Glands of the well-grown male porpoise. About one-third the natural size. The relation of these glands to the wind-pipe, the pericardium, and to each other, is represented.

glandular tissue extended deeply between the structures situated at the root of the neck. That from the right lobe passed in front of the trachea, being in close contact with the anterior surface of that tube, to the left side, where it became connected to the deep process from the left lateral lobe. This transverse communicating portion extended behind the arch of the aorta, so that this vessel, with its ascending carotid branches, was situated between the deeper and more superficial parts of the gland. Connected with the upper margin of the deep process from each lateral lobe was an elongated portion, which extended upwards on each side of the neck as far as the thyroid cartilage, being in close relation with the carotid vessels. These ascending prolongations of the thymus were thus brought into intimate relation with the lateral portions of the thyroid, so that at first it appeared as if they formed a common glandular mass with them. On a closer examination, it was found that they were not continuous, but intimately connected together by a little cellular tissue, on dividing which, the two glands could be separated from each other, without effecting any injury to their proper structure.

On referring to that part of Mr SIMON'S essay,* which treats of the com-

* Physiological Essay on the Thymus Gland, 1845.

parative anatomy of the thymus, I find that he gives an account of a dissection of this gland, which he made in a fœtal dolphin. He describes in this cetacean a pericardiac portion of the gland, from which long ascending processes proceed, which extend upwards in close contiguity with the vertebræ, as high as the level of the upper part of the trachea, and then bending inwards in front of that tube, so as to join in the middle line. The figure which he appends, illustrating this description, closely corresponds with the appearances I have seen both in the fœtal porpoise and in the smaller well-grown animal. I cannot, however, agree with Mr SIMON in considering this median tracheal portion as forming a part of the thymus. I am disposed to regard it as the thyroid, and as such I have described it in the former part of this paper. My reasons for doing so are the following:—It is situated exactly in the position of the thyroid gland; it possesses a perfect continuity of gland-structure from side to side, so that it does not present the same subdivision into lobes which is characteristic of the thymus; its capsule is much more adherent than that of the thymus, and it can be separated from the ascending processes of the pericardiac portion of the thymus by carefully removing the thin layer of cellular tissue which connects it with them. Moreover, there is no other structure, either on the front or sides of the trachea and larynx, which can be looked upon as constituting a thyroid gland in these mammalia, if this is not regarded as such.*

The persistence of the thymus gland in an animal so well grown as this porpoise is a fact of considerable interest, especially if we take into consideration its large size. That it was in a condition perfectly capable of performing its functions, and not merely a collection of fat-cells, as is generally the case where the gland in the human subject apparently persists for some years after birth, I was enabled to prove by a microscopic examination. On submitting a portion of the gland to a magnifying power of 200 diameters, I found it to consist of lobularly arranged masses of small closely-packed corpuscles, about the size of, and a little larger than, the red corpuscles of the human blood, presenting, in fact, a structure exactly similar to that with which we are familiar in the fœtal gland. We are furnished by this illustration with additional evidence of the fact, so especially insisted on by HAUGSTED and SIMON, that the thymus gland is not merely a fœtal structure, but that it plays an important part in the animal economy for some time after birth. As I had an opportunity of comparing it at the same time with the gland in the fœtal porpoise, there could be no doubt that it had grown considerably after birth, and apparently in a ratio closely corresponding with that of the growth of the animal.

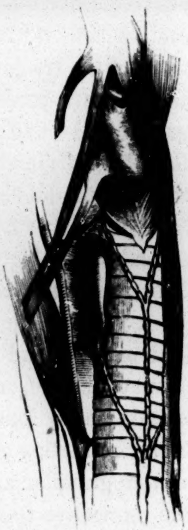
* Since this paper was read to the Society, I have dissected the neck of a fœtal Dolphin, probably the young of a bottle-nose (D. TURSIO). This dissection confirms the opinion I had arrived at and stated in the text, viz., that the glandular structure in front of the upper part of the trachea in the genus Delphinus is the thyroid, and not merely a part of the thymus.

The close connection which I have now shown to exist between the thymus and thyroid glands in these porpoises, strongly indicates that they most probably have originated in a common structure. This view of the common origin of these glands was prominently announced by Professor GOODSIR, in a paper in the Philosophical Transactions,* published many years ago. His investigations were conducted on the embryoes of sheep. He describes these glands as, together with the supra-renal bodies, developed from the remains of the blastodermic membrane extending along each side of the spine, from the Wolffian bodies to the base of the cranium,—a separation taking place between them in the process of development.

The porpoise is not, however, the only mammal in which, in the non-fœtal state, a connection may be seen to exist between the thymus and thyroid bodies.

In a fine specimen of an adult male Hartebeest (*Bubalus caama*), in which I dissected some time ago these glands, I found the lateral lobes of the thyroid entirely separated from each other, and lying on the sides of the upper end of the trachea. Connected with the lower part of each of these lobes was a long slender process of gland substance, which descended along the sides and front of the trachea, until it reached the fourteenth ring, when the processes from each side became connected together. At this spot they united with another slender process of a similar structure, which descended from the sides of the larynx. The common gland-mass, formed by the union of these processes, now passed down the front of the trachea, and beneath the sternum, into the anterior mediastinum, undergoing, immediately above the sternum, a considerable augmentation in size. That portion of the structure which was situated at the upper part of the trachea received its supply of blood from the arteries which supplied the thyroid gland. On examining this glandular substance microscopically, I found it to correspond in structure with the thymus gland, for it was essentially composed of numerous small circular corpuscles. Its structure and position warrant us in regarding it as a persistent thymus, and its close relation to the thyroid points to the conclusion that it has been developed along with it.

Fig. 2.



View of one lateral lobe of the Thyroid and of the slender processes of the Thymus of the Hartebeest, about one-third natural size.

In a dissection which I recently made of the thymus and thyroid in the Nylghau (*Antilope picta*), I obtained several very interesting facts connected with these glands. The animal which I examined was presented to the Anatomical Museum of the

* On the Supra-renal, Thymus, and Thyroid bodies, 1846.

University by the Marquis of Breadalbane. It was a very large example of an adult male, its proportions exceeding in every direction those given by Dr William Hunter, in his description of the Nylghau.* The thyroid gland was exposed in the usual way. It was found to consist of two entirely distinct lateral halves. Each half was seated quite at the posterior part of the side of the air-tube, the upper end being in relation with the outer surface of the cricoid cartilage, the lower end reaching to the side of the fourth tracheal ring. The two lobes were thus separated from each other by the entire width of the trachea. The lobes, wide at their upper ends, gradually became narrower as they extended down the side of the trachea, until they terminated below in an almost pointed extremity. Branches from the great artery of the neck passed both to the upper and lower ends of each lobe. On the anterior surface of the trachea, as well as on the crico-thyroid membrane, in the interval between the lobes of the thyroid, scattered lobules of glandular tissue of a slightly reddish tint were seen. These were not connected with the thyroid, but were lying in the cellular tissue between its lobes. Extending for some distance down the front of the trachea, scattered lobules of a similar glandular substance were found, separated from each other by varying intervals. About thirteen inches above the sternum the gland-lobules became much more closely connected together, and formed two long lines of glandular tissue which extended downwards on the front of the trachea. Immediately above the sternum they became wider, and, in this manner, passed beneath that bone for a short distance, lying in front of the great blood-vessels. Small arteries derived from the carotid trunk passed to this long line of gland-substance. This gland, from its position, was evidently the thymus, the lobules of which, closely aggregated together below, were separated from each other by varying intervals at the upper part of the trachea, some even extending as high as the crico-thyroid membrane. It was thus brought into close relation to, although not actually in contact with, the thyroid.

A microscopic examination satisfied me that it was the thymus,—the great bulk of the gland being composed of collections of small colourless corpuscles, about the size of, or a little larger than, the red corpuscles of human blood, arranged in a distinctly lobular manner. In some parts of the gland were scattered about highly refracting globular particles of varying size, probably fat. They presented a more granular aspect than is usual with oil-globules. Lying here and there in the connective tissue between the lobules of the gland were numerous crystals, sometimes aggregated together in irregular masses, at others arranged in lines, and in some cases scattered about in an indefinite manner. These crystals were all of a prismatic shape, many of them distinctly three-sided, presenting a close resemblance to the crystals of the ammoniaco-magnesian phosphate occasionally

* Philosophical Transactions, 1771.

met with as a urinary deposit. They were soluble in acetic acid without effervescence. The existence of crystals scattered freely about in the cellular tissue of the animal body is, so far as my observation extends, a fact of very unusual occurrence. From the position and microscopic character of this gland, there could be no doubt that it was the thymus.

The evidence that we have now obtained, both by the dissection of this Nylghau and the Hartebeest, shows us, that in these Antilopidæ the thymus is a permanent gland; for there could be no question but that both these animals had reached the adult period of life, and even acquired a considerable age,—their large size, and the worn appearance of the teeth, rendered this sufficiently manifest. So far, then, as regards these animals, the thymus must be looked upon as possessing a more enduring function than has hitherto been ascribed to it in the economy, —not disappearing, or altogether degenerating, in the early period of extra-uterine life, but persisting, even in the adult animal, probably throughout its entire existence.

In conclusion, I may state that I have seen in the human subject indications of a close connection between the thymus and thyroid glands. I have notes of an examination which I made of a child between two and three months old, in which long ascending processes passed upwards from the lobes of the thymus, in front of, and to the sides of, the trachea, as high as the lateral lobes of the thyroid gland, with which they were closely connected by cellular tissue. Each of these ascending processes received a branch from the inferior thyroid artery. This case furnishes us with an example of the thymus receiving a considerable portion of its vascular supply from the artery of the thyroid. The converse of this, viz., the thyroid obtaining a large share of blood from the artery of the thymus, may also occasionally be seen. In a subject in the dissecting-room, I observed the internal mammary artery, which may be regarded as the great thymic trunk, give off a large branch, which ascended, on the right side of the trachea, to the right lateral lobe of the thyroid gland.

XII.—*On the Climate of Edinburgh for Fifty-six years, from* 1795 *to* 1850, *deduced principally from Mr Adie's Observations; with an Account of other and Earlier Registers.* By JAMES D. FORBES, D.C.L., F.R.S., Sec. R.S. Ed., Professor of Natural Philosophy in the University of Edinburgh. (With two Plates, XVIII. and XIX.

(Read 5th March 1860.)

§ 1. Early Observations.
§ 2. Mr Adie's Observations.
§ 3. Annual and Monthly Mean Temperatures.
§ 4. Fall of Rain.
§ 5. Succession of Seasons, 1795 to 1850.
§ 6. On the Annual Curve.
§ 7. Influence of Seasons on the Price of Corn.

1. The late Mr ALEXANDER ADIE, optician, and Fellow of the Royal Society of Edinburgh,* was so generally known to be a zealous and careful observer of meteorological instruments, that an attempt to combine the results deducible from his labours carried on (though with one long break) over more than forty years, cannot be otherwise than interesting.

2. The plan of superintending the careful reduction of the thermometrical part of Mr ADIE's registers occurred to me a long time ago, but circumstances prevented the execution of it until two or three years since, when, through the kindness of Mr ADIE and his family, the whole of the manuscript observations, commencing with 1795, were put into my hands, and the Council of the Royal Society of Edinburgh provided sufficient funds for the employment of computers for reducing them.

3. The work has proceeded with frequent interruptions, but is at length complete. Before I proceed to detail the particulars of the reductions and their results, I will give a short account of the earlier observations on the climate of Edinburgh which I have been able to trace, some of which perhaps have hitherto escaped notice.

SECT. 1. *On the Earlier Recorded Observations on the Climate of Edinburgh.*

4. I have been fortunate enough to discover an old printed Register of Meteorological Observations at Edinburgh, extending from June 1731 to May 1736. It is contained in five successive volumes of "Medical Essays and Observations published by a Society in Edinburgh," which reached a third edition in 1748, and it is the one from which I quote.

5. This register appears to have been made with remarkable care, ndd most likely by one observer, and in the same locality, for the above-mentioned period, and probably longer, as I judge from the mention of it in MARTINE's Essays.†

* Some account of Mr ADIE's personal history and labours will be found in the Vice-President's Address for the Session 1859–60 (Proceedings of the Royal Society of Edinburgh, vol. iv. pp. 225–27.)

† Essays and Observations on the Construction and Graduation of Thermometers by GEORGE MARTINE, M.D., 2d edit. 1772, p. 48.

The Observatory was situated in the town of Edinburgh, about 270 feet above the sea.* The thermometer was sheltered by a case well perforated with holes to admit the air.† It was filled with alcohol, and graduated, not, as now, into degrees, but into inches and tenths. But the reference to Fahrenheit's scale becomes easy, since we are told (p. 7), that "the freezing point is at 8 inches 2 tenths; and the heat of a man in health raises the spirits to 22 inches 2 tenths." The former point of course corresponds to 32° Fahr.; the latter was found by Dr MARTINE to be 97° Fahr. by actual experiment on the person who graduated the Edinburgh thermometer.‡ Hence it is easy to form a table for reducing the "Edinburgh Scale" to Fahrenheit's; but it may be sufficient to adopt a reduction which is to be found already made at page xiv. of the preliminary matter to the third volume of "Essays of the Philosophical Society in Edinburgh," published in 1771. The observations there tabulated are evidently identical with the observations already described, although these are not there directly referred to. It would also appear that blood-heat was reckoned at 96° instead of 97°, as I find by comparing the numbers in the "Medical Essays" with those of the Philosophical Society. If we assume (as is reasonable) MARTINE to be correct, the numbers in the foregoing tables ought to be slightly raised; but for the mean annual temperature the difference would be less than a quarter of a degree.

6. I regret that it is not in my power to throw any light on the name of the person by whom these records were made; but he was in all probability a medical man.

7. I ought to add that the barometer, hygrometer, wind, weather, and amount of rain, are all carefully entered. The observations were almost invariably made twice a-day, the first nearly always at 9 A.M., the second at an hour (usually between two and six) which varied with the season of the year.

8. Confining our attention to the thermometrical observations, they require a correction for the varying hour at which the afternoon observations were made at different seasons of the year. Taking a sort of average, I have applied the following tabular corrections to the reduced observations as given in the "Essays of the Philosophical Society" above referred to. The second line contains the reductions for the observations made in 1764–70, which will be immediately referred to:—

Years.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1732–35, ...	−0·3	−0·5	−1·0	−2·1	−1·7	−1·3	−1·9	−1·1	−1·8	−0·8	−0·5	−0·2
1764–70, ...	+0·9	+1·3	+1·8	+2·2	+1·4	+1·1	+1·1	+1·1	+1·5	+1·0	+1·0	+0·5

9. The *earlier* of these series of observations, it is to be observed, was adapted to the *Julian, or old style*. These tabular corrections are taken from M. DOVE'S reductions of the Leith hourly observations.§

* Medical Essays, i. p. 6.—Most likely in the neighbourhood of the present Royal Exchange.

† Ibid. p. 8. ‡ MARTINE'S Essays, p. 48. § British Association Reports for 1847.

10. The next observations we find recorded are in the same volume (the third) of the "Essays of the Philosophical Society in Edinburgh" from which I have already quoted. They embrace the years 1764 to 1770 inclusive, and consist of two sets, one made at Hawkhill, situated between Edinburgh and Leith, at 103 feet above the sea, the other at Edinburgh itself. If we assume that the latter set was made in the same locality as the observations of 1732–36, the height above the Hawkhill Observatory would be 167 feet. Both sets were made uniformly at the hour of 8 A.M., and a correction has been applied to the monthly means to reduce them to the average, to the extent indicated in Art. 8. The Hawkhill observations were continued at least until 1776 by Mr MACGOWAN, and the results are contained in the first volume of the "Edinburgh Transactions," page 333. They are also included in this Table, with the same correction for the hour of observation (8 A.M.)

EDINBURGH (*reduced*).

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1732	34·4	41·5	41·0	41·8	48·6	57·7	56·1	54·2	48·5	44·4	36·5	35·9	45·0
1733	38·1	39·3	38·8	45·4	50·9	58·1	59·3	53·7	48·5	43·5	43·4	43·2	46·8
1734	34·4	42·0	44·2	48·2	48·1	56·3	57·1	54·2	47·6	40·8	36·5	35·9	45·4
1735	36·3	35·1	38·8	43·6	48·1	54·9	57·5	56·5	47·6	43·1	42·0	38·2	45·1
1764	34·6	35·4	40·3	45·0	53·5	55·9	60·0	57·5	51·9	46·6	40·2	36·7	46·5
1765	40·9	34·5	40·9	45·7	49·4	53·3	57·5	56·6	54·1	47·0	41·2	37·6	46·5
1766	38·1	31·1	38·7	46·1	46·3	55·7	59·3	59·5	46·9	46·4	43·7	37·9	45·8
1767	31·2	41·3	39·2	42·6	47·1	52·9	55·7	57·8	55·2	45·5	42·5	37·6	45·7
1768	33·2	37·8	38·6	46·2	50·0	54·2	57·9	57·5	50·8	42·6	38·8	37·5	45·4
1769	33·8	35·2	40·6	45·2	49·0	53·2	59·0	55·4	53·3	45·2	39·2	37·8	45·6
1770	37·1	38·8	34·4	40·6	46·1	52·4	55·7	57·2	53·6	44·0	37·3	34·9	44·3
											Mean of 11 years,		45·64

HAWKHILL (*reduced*).

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1764	36·6	38·6	40·0	46·3	54·3	57·5	61·4	59·0	52·6	47·3	39·2	36·2	47·4
1765	40·1	33·5	41·3	46·8	54·0	55·6	60·1	58·1	53·3	48·0	37·9	35·7	47·0
1766	35·0	35·1	39·4	48·1	47·9	55·9	60·6	60·9	53·2	47·4	43·8	37·8	47·1
1767	32·0	41·7	40·2	47·1	50·8	55·0	58·1	61·2	56·2	46·5	43·8	39·4	47·7
1768	33·5	38·8	41·5	49·0	54·6	56·4	60·0	60·1	52·6	47·8	40·9	39·2	47·9
1769	35·6	37·2	42·9	47·8	52·5	56·3	61·8	57·7	55·5	46·5	40·9	40·5	47·9
1770	39·5	41·6	37·1	43·8	50·0	55·2	58·6	59·6	56·7	46·6	39·1	37·7	47·1
1771	34·1	37·9	37·7	43·9	51·8	56·8	59·6	57·7	53·2	47·8	42·9	41·8	47·1
1772	32·4	32·2	38·8	45·1	50·5	58·3	59·8	58·5	53·0	49·8	42·7	40·1	46·8
1773	39·5	36·4	43·9	47·8	50·0	56·3	58·8	59·4	52·8	47·0	39·2	36·9	47·3
1774	30·0	37·5	38·9	45·3	48·0	56·2	58·5	58·3	53·2	49·3	39·1	37·8	46·0
1775	38·7	40·4	41·8	49·0	54·1	57·7	60·2	58·7	54·8	46·3	39·0	39·1	48·3
1776	30·1	37·0	42·7	48·1	50·7	56·6	60·5	57·8	53·3	48·0	42·0	38·3	47·1
											Mean of 13 years,		47·28

11. The two sets of observations are each consistent among themselves; but the average difference of the two series, amounting to 1°·6 in excess for the mean temperature of Hawkhill above Edinburgh, is greater than the difference of level and exposure would seem to warrant. Even after applying a correction of +0°·25 to the Edinburgh observations, deduced from MARTINE's estimate of blood heat (Art. 5), these averages appear to be too low, whilst those of the Hawkhill observations agree well with the modern ones contained in the sequel of this paper.*

12. Professor PLAYFAIR appears to have commenced in 1794 a register in Windmill Street (near George Square), Edinburgh, 265 feet above the level of the sea. The results are published in the Edinburgh Transactions, Vols. IV. and V., from 1794 to 1799 both inclusive. The hours of observation were nearly 8, 2, and 10 (not 8, 12, and 10, as stated by M. DOVE†), the middle observation being chosen so as to fall nearly at the moment of highest temperature.

Mean Annual Temperature of Edinburgh.

Years.	Playfair, 8^h, 2^h, and 10^h.	Adie, 8^h and 8^h.	Difference.
1794	50°·32	° ...	° ...
1795	47·75	45·67	−2·08
1796	48·10	46·46	−1·64
1797	48·04	46·33	−1·71
1798	49·28	47·59	−1·69
1799	46·13	44·44	−1·69

The difference is striking, and nearly constant. Sir D. BREWSTER attributes it to the radiation of heat from neighbouring houses at the midday observation.‡ At all events, Professor PLAYFAIR's observations seem to be in error.

13. The only farther contribution I have to make to the older series of observations is to mention that in Mr ADIE's earliest Register Book, mentioned below, I find a memorandum that the mean temperature of the year 1787 was 46°·44; of 1788, 46°·191; and of 1789, 46°·573; but the authority is not given.

SECT. 2. *On Mr Adie's Thermometrical Observations generally, and their Reduction.*

14. The observations of Mr ADIE on the temperature of Edinburgh have hitherto been known by their periodical publication for some years, commencing with 1824, in Sir D. BREWSTER's "Edinburgh Journal of Science," from whence they have been quoted by M. DOVE in his various writings.

* Farther references to Mr MACGOWAN's observations will be found in the "London Philosophical Transactions" for 1775, and in the Edinburgh Transactions, vol. iv. p. 214; but I have not been able to discover any continuation of the observations later than 1776.

† Not unnaturally, since in the Tables themselves the word "noon" is used to denote the midday observation. Compare p. 214 of the paper in vol. iv. of the Transactions.

‡ Edin. Trans. ix. p. 209.

15. The original observations were far more extensive. Stimulated probably by Professor PLAYFAIR's example and advice, Mr ADIE commenced what appears to have been a very careful register of the thermometer, barometer, wind, and rain, on the 1st January 1795. After continuing this register with great punctuality for more than ten years, it came abruptly to a close about the middle of 1805. It seems certain that Mr ADIE then discontinued it, not from any want of interest in the subject, but because he considered that he had amassed sufficient materials for ascertaining the peculiarities of the climate of Edinburgh. For he reduced these ten years' observations with care, and not only so, but projected the whole in neat curves now in the possession of his family. These observations were made in Merchant Court, a locality now apparently extinct, but which was close to Merchant Street, near George IV. Bridge, in the old town of Edinburgh. Its elevation above the sea was, according to Mr JAMES JARDINE,* 230 feet. The distance from Windmill Street, the locality of Professor PLAYFAIR's observations, was inconsiderable. The observations were made at 8 A.M. and 8 P.M.

16. Nearly fifteen years elapsed from 1805 without observations being made. I shall afterwards state the source whence I have attempted to supply this blank.

17. In 1821 Mr ADIE resumed his observations at his villa of Canaan Cottage, in a sheltered valley about a mile and a quarter south from his former locality. Its elevation was 260 feet above the sea.† The observations of the common thermometer and barometer were made at 10 A.M. and 10 P.M. instead of eight o'clock, as formerly. From 1822 the observations included the maximum and minimum temperature.

18. These observations were continued until 1850 inclusive, by Mr Adie or some member of his family. But it is important to observe, that from the middle of May 1831 to the middle of May 1838, the locality was removed to No. 9 Regent Terrace, on the Calton Hill, in the new town of Edinburgh, 246 feet above the sea, about five furlongs N.E. from his first station in Merchant Court, but in a far opener and more airy situation. In 1838 the old residence at Canaan Cottage was resumed.

19. Thus we have consecutive observations from 1795 to 1804 both inclusive; and again consecutive observations from 1821 to 1850 both inclusive, at two localities distinct from the former. The changes of locality and exposure are no doubt unfavourable to the perfect comparability of these observations. Nevertheless the considerable continuity of the observations in each locality enables me to affirm, after comparing the mean results, that the change of position (the

* See Sir D. BREWSTER's Memoir on the Mean Temperature of the Globe (Edin. Trans. vol. ix. pp. 209, 210), where also the mean temperature is deduced from Mr JARDINE's observations on the springs of the Pentland Hills to be 47°·1.

† Edinburgh Journal of Science, vol. i. In later volumes it is stated at 300 feet, but this is certainly too high. By the Ordnance Survey Map it would appear to be about 280 feet.

height above the sea not having materially varied) has very slightly, if at all, affected the indications of the thermometer.

20. The observations are recorded in seven quarto paper books, all apparently original. My attention has been almost entirely confined to the *thermometrical* observations, though I have also used the monthly totals of the rain-fall which were first collected by Mr JOHN ADIE.

21. My first business was to obtain the mean temperature of each day of the forty years' observations. This was done with great care by Mr GRASSICK, clerk in Messrs ADIE and SON's establishment. For the ten and a half years, 1795–1805, the mean of the eight o'clock morning and evening observations of the thermometer was taken and entered in vertical columns under each day of the year.

22. Beginning with 1822, the mean of the maximum and minimum temperature is taken to represent the mean of the day; for 1821 *only* the mean of the 10 A.M. and 10 P.M. observations was used. I have not attempted any correction for the more accurate estimation of the mean temperature than is given by these several times of observation. They are known all to coincide closely with the mean in the long-run. The degree of coincidence of the mean of the 10 A.M. and 10 P.M. observations with the mean of the maxima and minima may be appreciated by an examination of Mr ADIE's printed registers in the Edinburgh Journal of Science. As a *general* rule, I am averse to the application of corrections to particular meteorological data, depending upon averages merely, because they fail to reproduce the very peculiarities of which we may be in search. In deducing probable results for the climate at one place from that at a neighbouring locality, the possible error arising from such corrections must be submitted to. But in most other cases I prefer using, when admissible, those observations in their pure and simple form which give most nearly the mean temperature of the day (omitting any others) to applying to individual results any considerable correction or factor derived from long averages merely. Such corrections may, if wished, be easily applied to the *final average* of a long course of observations, to which alone they are strictly applicable.

23. The sums and means of each column (Art. 21) of daily mean temperature were taken for four periods of ten years each, into which the whole of Mr ADIE's observations were divided; viz., for the periods 1795–1804, 1821–30, 1831–40, 1841–50. The total averages were then taken.

24. In like manner, the monthly averages for each year were taken, and the whole combined in the usual way. The mean temperature of the month, for each period of ten years, was first taken by the mean of the averages for each day of the month (or means of the vertical columns), and again, by the mean of averages of the months for each year separately.

25. Another check on the accuracy of the computer was obtained by the circumstance that Mr ADIE had already, in by far the majority of instances, taken the means himself. Mr GRASSICK's calculations were made independently of these

determinations, and where any discrepancy appeared, the cause was carefully sought out.

26. Farther, the accuracy of the copy from the original registers, and of each part of the calculations, was tested in a great many instances (taken at random) by Mr Balfour Stewart (now of Kew Observatory), in whose exactness I have the utmost confidence. Although some errors were thus detected, they were not sufficiently numerous or important to shake my confidence in the care with which the reductions had been made, but rather indeed confirmed it.

27. I ought to add, that the observations were all made with instruments manufactured by Mr Adie himself, and certainly equal in accuracy to any then constructed. I have not been able to ascertain when or how often the thermometers were renewed. We must therefore rely on their general exactness, without attempting a correction for index error.

28. The thermometers were commonly read to whole degrees merely. Consequently, in taking the mean temperature of the day from two observations, we have not usually to do with any fractions differing from 0°·5. To save room, I have adopted, in the MS. calculations, a plan which may be usefully employed in all such cases. I have written such a temperature as 52·5 thus, 52˙, and have allowed for these half degrees in making the summations. Where *quarter degrees* occurred, the nearest *whole* degree was written, and this little error is evidently self-compensatory in the long-run.

Sect. 3. *On the Annual and Monthly Mean Temperatures of Edinburgh for Fifty-six years.*

29. A peculiar interest attaches to long-continued series of thermometrical observations in one locality. When made by one observer, and with comparable instruments, the interest is greatly heightened. We then see clearly the great extent of what M. Dove calls the "Non-periodic fluctuations" of temperature, and the great length of time required to attain any certainty, even as to the precise mean temperature of a place, still more the peculiarities of the inflection of the diurnal and annual curves of temperature.

30. A slight inspection of M. Dove's large collection of monthly average temperatures,* will show in how few instances anything like fifty years of continuous thermometrical observations can be depended on. The interesting deductions by M. Quetelet from his own perfectly comparable observations at Brussels for only twenty years, show how much may be done to reduce the apparently lawless changes of climate to order, by the judicious combination of long averages.† I have kept M. Quetelet's reductions in view, in the course of those which follow.

* See his Memoirs in the Berlin Transactions. In the Index to these which I have made and printed in the Edinburgh Transactions, vol. xxii. p. 75, I have indicated by an asterisk the stations where the observations have been most continuous.

† Mem. de l'Acad. de Bruxelles, tom. xxviii. Paper read June 1853.

31. The unfortunate blank in Mr ADIE's observations from 1805 to 1820 inclusive, detracted considerably from their interest, and I used every effort to discover some other register which might be used to supply the defect. None from the immediate neighbourhood of Edinburgh, however, appeared. But my attention was directed by M. DOVE's summaries to a register of twenty years' continuance, kept at Dunfermline by the Rev. Mr FERGUS, which extended over the missing years, and which farther indicated a climate remarkably agreeing with that of Edinburgh, not only in the annual mean, but in the partition of temperature throughout the seasons.

32. The town of Dunfermline lies thirteen miles in a right line to the N.W. of Edinburgh. It is little more than three miles distant from the estuary of the Forth, and about 300 feet above its level. I shall detail in a short paper on the climate of Dunfermline, following the present one, the fortunate circumstances which put me in possession of Mr FERGUS's original registers, extending over a period nearly equal to those of Mr ADIE.

33. In order to reduce the Dunfermline temperatures to those of Edinburgh, I selected the ten years 1821–30, during which observations were made contemporaneously at both places; and taking the monthly means, and averaging the differences for each month of the year, I obtained the following numbers for the reduction of the Dunfermline monthly mean temperatures at 9 A.M., to those of Edinburgh (mean of maxima and minima):—

January,	−0°61	July,	+0°32
February,	+0·19	August,	+0·67
March,	+1·46	September,	+1·20
April,	+1·08	October,	+0·71
May,	+0·66	November,	+0·11
June,	0·00	December,	−0·29

If these corrections be projected, an annual curve passes very fairly through them, indicating two maxima in March and September, and two minima in June and December.

34. The corrections derived from the table above were employed to reduce the Dunfermline observations of the years 1805–20 (deficient in Mr ADIE's series) to Edinburgh. It is to be observed, that these corrections are irrespective of the error of either thermometer, and merely reduce the readings of the one to those of the other. I have distinguished the derived observations in the following table by the letter D. While I neither claim for them the original worth and precision of Mr ADIE's observations, nor rely too much on the universal application of the reductions from one locality to another, I believe that they will be found to indicate in a trustworthy manner the specific characters of those seasons which would otherwise have been defective in the series.

TABLE I.—Mean Monthly Temperature at Edinburgh for 56 Years.

N.B.—The numbers followed by D are deduced from the Dunfermline Observations.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Annual Means.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1795,	30·03	30·43	37·26	44·20	48·88	52·30	57·32	59·19	56·98	50·24	37·80	43·40	45·67
1796,	44·11	40·03	38·27	48·43	48·17	55·35	56·67	59·17	54·30	43·75	38·26	31·03	46·46
1797,	39·58	42·26	38·93	43·68	50·62	53·08	58·88	57·04	51·03	43·58	38·50	38·74	46·33
1798,	37·09	37·50	39·35	48·13	53·40	61·36	59·79	58·70	53·45	47·41	39·13	35·72	47·59
1799,	36·20	34·87	36·82	39·65	47·3*	54·18	57·05	55·43	52·63	44·51	40·30	34·30	44·44
1800,	34·53	34·69	36·79	45·00	49·06	54·48	60·72	59·31	53·68	46·32	38·70	35·12	45·70
1801,	37·77	38·21	39·90	43·95	50·61	56·58	56·95	60·21	55·75	48·61	39·01	32·53	46·67
1802,	37·12	36·57	40·66	45·90	48·45	55·83	55·93	59·72	54·73	49·14	41·10	37·16	46·86
1803,	35·19	36·82	41·05	46·20	49·89	55·26	62·74	58·32	51·06	46·66	38·48	37·91	46·63
1804,	39·77	35·22	37·17	41·82	53·98	59·26	58·87	57·93	57·10	49·26	41·65	35·68	47·31
1805,	37·08	37·10	42·53	46·08	48·00	54·60	60·4 D	60·32	56·5 D	46·5 D	43·5 D	36·3 D	47·41 D
1806,	35·0 D	37·8 D	41·6 D	45·9 D	52·7 D	57·8 D	58·7 D	58·9 D	55·1 D	50·4 D	44·5 D	40·7 D	48·26 D
1807,	37·1 D	36·8 D	36·8 D	44·6 D	50·0 D	54·9 D	61·9 D	59·5 D	48·5 D	49·0 D	34·1 D	36·7 D	45·82 D
1808,	35·8 D	36·2 D	40·8 D	42·4 D	53·6 D	57·9 D	62·8 D	59·6 D	54·0 D	43·8 D	40·0 D	36·1 D	46·91 D
1809,	31·1 D	38·9 D	43·4 D	41·3 D	53·4 D	54·7 D	57·7 D	56·8 D	54·1 D	52·3 D	41·0 D	36·8 D	46·80 D
1810,	37·1 D	36·1 D	37·9 D	45·1 D	46·6 D	57·1 D	56·8 D	58·3 D	55·2 D	49·7 D	39·5 D	35·8 D	46·26 D
1811,	34·1 D	37·5 D	43·7 D	45·4 D	51·2 D	54·2 D	58·2 D	55·8 D	53·9 D	50·8 D	42·9 D	36·2 D	47·00 D
1812,	35·5 D	39·5 D	37·1 D	40·5 D	49·1 D	54·4 D	55·6 D	56·1 D	53·9 D	47·3 D	39·6 D	35·3 D	45·32 D
1813,	35·9 D	40·0 D	44·2 D	43·9 D	48·3 D	55·7 D	58·0 D	56·9 D	53·8 D	44·7 D	38·8 D	37·6 D	46·48 D
1814,	27·7 D	35·8 D	39·4 D	48·3 D	48·6 D	52·6 D	58·4 D	56·8 D	54·5 D	45·6 D	39·1 D	35·7 D	45·21 D
1815,	33·4 D	41·1 D	43·0 D	46·0 D	50·9 D	55·1 D	57·6 D	57·0 D	53·5 D	47·9 D	37·2 D	34·1 D	46·40 D
1816,	35·2 D	35·3 D	38·2 D	41·0 D	49·4 D	53·4 D	54·8 D	54·5 D	51·3 D	46·6 D	38·5 D	35·4 D	44·46 D
1817,	38·0 D	39·5 D	39·7 D	44·7 D	45·9 D	54·1 D	56·3 D	54·1 D	53·8 D	42·6 D	44·2 D	35·4 D	45·69 D
1818,	36·9 D	36·5 D	38·2 D	40·7 D	50·0 D	59·0 D	59·7 D	56·2 D	52·9 D	52·4 D	46·9 D	39·7 D	47·42 D
1819,	37·6 D	36·6 D	42·2 D	45·1 D	49·3 D	54·0 D	57·9 D	61·7 D	53·5 D	46·1 D	37·3 D	34·0 D	46·27 D
1820,	31·6 D	40·0 D	40·7 D	46·8 D	50·2 D	54·0 D	57·3 D	55·9 D	51·8 D	44·3 D	42·1 D	38·7 D	46·11 D
1821,	38·29	39·21	41·40	47·58	46·50	52·15	56·87	57·55	56·46	49·89	42·60	40·80	47·44
1822,	39·05	40·58	43·74	45·53	52·45	59·22	58·05	57·00	50·31	47·79	44·05	36·11	47·82
1823,	31·06	34·41	40·52	42·40	51·34	53·27	56·40	55·58	51·92	44·85	44·56	37·32	45·30
1824,	39·89	39·03	39·64	45·22	50·08	56·65	59·89	57·22	54·56	45·76	40·73	38·42	47·26
1825,	39·09	38·96	41·19	46·58	50·72	56·70	61·40	60·06	56·91	50·14	38·51	37·97	48·19
1826,	33·19	41·75	41·84	46·76	51·79	61·28	61·98	60·98	54·63	49·92	38·75	41·06	48·66
1827,	35·42	33·98	40·06	45·05	50·77	56·15	58·45	55·24	54·98	50·13	42·80	42·24	47·11
1828,	39·45	40·09	42·87	45·23	51·22	56·86	57·63	56·98	54·51	48·47	44·88	43·34	48·46
1829,	32·08	38·77	39·68	41·90	51·64	56·35	56·55	54·05	50·30	45·93	39·53	35·97	45·23
1830,	34·32	36·03	44·21	46·63	49·74	51·98	57·72	52·68	52·15	48·51	42·35	35·45	45·98
1831,	34·69	38·68	42·29	45·01	48·80	50·30	59·39	60·10	55·28	52·97	40·38	41·85	47·48
1832,	39·13	40·55	41·82	45·80	48·68	55·88	57·71	57·36	54·05	49·74	41·43	40·55	47·72
1833,	34·69	39·52	38·87	44·41	55·82	55·55	58·87	54·55	52·96	48·93	41·76	40·30	47·19
1834,	41·42	40·50	42·89	45·05	52·26	56·88	59·26	58·37	54·02	48·85	43·18	42·22	48·74
1835,	37·88	39·62	40·56	44·63	48·96	54·31	57·55	59·09	52·21	45·63	42·40	38·80	46·80
1836,	38·09	37·15	39·64	42·78	50·87	55·93	56·00	54·93	49·55	45·08	39·76	38·93	45·73
1837,	34·97	38·88	34·78	38·93	47·98	56·00	59·61	55·59	51·70	49·22	40·07	40·97	45·72
1838,	30·63	29·82	39·13	41·14	46·04	54·53	59·15	56·87	53·53	47·39	37·93	40·53	44·72
1839,	35·50	37·85	38·24	43·50	49·13	55·75	58·63	56·56	53·41	47·37	42·31	38·08	46·36
1840,	39·23	37·47	41·13	48·36	48·32	55·11	55·93	59·14	51·40	46·29	41·65	36·58	46·72
1841,	33·43	37·87	46·48	45·35	52·03	53·86	56·35	57·30	54·41	44·56	38·98	38·92	46·63
1842,	34·98	40·02	42·51	46·00	51·68	57·08	56·25	59·93	55·10	45·42	40·93	45·59	47·96
1843,	39·42	34·28	42·32	45·63	47·13	52·20	58·78	57·90	57·10	44·89	44·13	47·70	47·62
1844,	41·16	35·77	41·40	49·66	48·82	55·05	56·89	55·55	53·15	47·08	43·26	32·98	46·73
1845,	36·56	35·21	36·80	45·11	48·13	56·81	55·09	55·82	54·25	49·37	43·38	38·77	46·27
1846,	42·06	44·85	42·68	44·73	53·18	61·60	59·43	59·90	59·30	48·19	44·85	34·39	49·60
1847,	35·95	35·84	42·03	43·35	50·59	55·86	61·77	57·56	51·48	48·95	45·56	39·72	47·39
1848,	33·64	40·07	41·56	44·06	55·48	54·93	59·18	54·06	53·75	46·61	40·23	40·45	47·00
1849,	37·09	42·41	42·58	42·71	51·03	52·91	56·75	57·01	52·41	44·85	41·78	36·64	46·51
1850,	31·50	41·75	42·37	46·36	48·29	58·45	59·11	56·82	52·36	47·49†	41·17†	38·57†	47·02
Mean of the whole,	36·15	37·90	40·55	44·65	50·18	55·55	58·28	57·41	53·66	47·50	41·00	37·98	46·75
Mean of the Edinburgh Observations only,	36·64	37·92	40·58	44·84	50·26	55·65	58·29	57·49	53·72	47·49	41·17	38·57	46·88

* Interpolated.

† Supplied from the Means.

35. With a view to trace more intelligibly the specific characters of the different seasons, and in the hope of perhaps distinguishing in them something of a periodic or recurring character, I had the whole of these monthly temperatures projected in the form of fifty-six annual curves of temperature. The result, however, does not seem at present to warrant the labour and expense of reducing and engraving them. Looking, however, in a general way at these curves, or at the numbers in the preceding table, we note three leading characteristics of any year. I. The mean temperature of the year, or the position of the line of abscissæ of the curve for that year. II. The annual range due to season. III. The earliness or lateness of the season, or the period of culmination of the curve for the year.* We shall consider these elements of climate more particularly.

36. I. *Mean Temperature of the Year.*—The mean of the whole period, deduced from nearly 35,000 observations, is 46°·75, or if we exclude the Dunfermline observations, 46°·88.†

The highest annual mean was that of 1846, amounting to, ...	49°·60
The lowest was that of 1799, ...	44·44
The range,	5·16

The higher limit was nearly touched in 1826 and 1834; the lower limit in 1816 and 1838.‡ The following table contains the order of the years, taken with respect to mean temperature, beginning with the highest:—

TABLE II.—THE SEASONS ARRANGED ACCORDING TO THE MEAN TEMPERATURE, BEGINNING WITH THE HIGHEST.

1.	1846	8.	1822	15.	1805	22.	{1811	29.	1840	36.	1815	43.	1830	50.	1812
2.	1834	9.	1832	16.	1847	23.	{1848	30.	1801	37.	1839	44.	1807	51.	1823
3.	1826	10.	1843	17.	1804	24.	1808	31.	{1803	38.	1797	45.	1836	52.	1829
4.	1828	11.	1798	18.	1824	25.	1802	32.	{1841	39.	{1819	46.	1837	53.	1814
5.	1806	12.	1831	19.	1833	26.	{1809	33.	1849	40.	{1845	47.	1800	54.	1838
6.	1825	13.	1821	20.	1827	27.	{1835	34.	1813	41.	1810	48.	1817	55.	1816
7.	1842	14.	1818	21.	1850	28.	1844	35.	1796	42.	1820	49.	1795	56.	1799

* In the usual approximate expression for the annual curve of temperature represented by the curve of sines, where t is the temperature of any day of the year, x the time reckoned from the commencement of the year, then, $t = A + B \sin (x + u_1)$. The three constants, A, B, and u_1, refer to the three particulars specified in the text. The equation to the annual curve will be more fully considered farther on (in § 6).

† It will be seen how nearly this coincides with Mr JARDINE's deductions from the temperature of springs, viz., 47°·08. (Art. 15, *note*).

‡ The mean temperature of Greenwich for seventy-nine years (1771–1849) is estimated by Mr GLAISHER at 48°·29, or only 1°·54 above that of Edinburgh. The fluctuation of the mean annual temperature at Greenwich was 6°·2, or within the period of the Edinburgh observations (1795–1850) 5°·6. (Phil. Trans., 1850.)

37. II. *The Annual Range*, as roughly represented by the difference of the hottest and coldest months, varied from 30°·7 in 1814 to 17°·9 in 1836. The mean is 24°·1.* The importance of this element in estimating the character of any year with respect to temperature, is well illustrated by comparing the years 1826 and 1828, which stand third and fourth on the list of mean annual temperature; but whereas the former was the hottest summer recollected in Scotland, the last was remarkably the reverse, the annual mean being kept up by the mildness of both the preceding and following winter. Table III. contains the years arranged according to the amount of the Annual Range, where it will be seen that 1826 stands *fourth* in order, and 1828 *fifty-fifth*.

TABLE III.—THE SEASONS ARRANGED ACCORDING TO THE DIFFERENCE OF HOTTEST AND COLDEST MONTHS, BEGINNING WITH THE GREATEST DIFFERENCE.†

1.	1814	8.	1801	15.	1847	22.	1837	29.	1811	36.	1818	43.	1813	50.	1849
2.	1838	9.	1850	16.	1820	23.	1843	30.	1804	37.	1802	44.	1845	51.	1816
3.	1795	10.	1803	17.	1798	24.	1827	31.	1844	38.	1839	45.	1824	52.	1821
4.	1826	11.	1846	18.	1848	25.	1829	32.	1806	39.	1822	46.	1835	53.	1834
5.	1796	12.	1808	19.	1831	26.	1815	33.	1841	40.	1799	47.	1817	54.	1832
6.	1807	13.	1809	20.	1823	27.	1833	34.	1825	41.	1840	48.	1812	55.	1828
7.	1819	14.	1800	21.	1842	28.	1805	35.	1830	42.	1810	49.	1797	56.	1836

38. It may be interesting to classify the years in the order of the mean temperature of the *hottest month*, distinguishing which month that is, as in the following Table:—

TABLE IV.—CONTAINING THE MEAN TEMPERATURE OF THE HOTTEST MONTH IN EACH YEAR.

1808	62°·8	July	1824	59°·89	July
1803	62·74	July	1802	59·72	August
1826	61.98	July	1818	59·7	July
1807	61·9	July	1837	59·61	July
1847	61·77	July	1804	59·26	June
1819	61·7	August	1834	59·26	July
1846	61·60	June	1822	59·22	June
1825	61·40	July	1795	59·19	August
1798	61·36	June	1848	59·18	July
1800	60·72	July	1796	59·17	August
1805	60·4	July	1838	59·15	July
1801	60·21	August	1840	59·14	August
1831	60·10	August	1850	59·11	July
1842	59·93	August	1835	59·09	August

* According to Mr GLAISHER, the mean difference of the hottest and coldest months at Greenwich for 79 years (1771–1849) is 28°·5, varying from 37°·1 to 21°·3. The climate of Greenwich is therefore more extreme than that of Edinburgh. The mean temperature of January is nearly a degree higher at Edinburgh than at Greenwich.

† In this Table the months in all cases belonged to the same Calendar Year.

TABLE IV. (*continued.*)

1806	58°·9	August	1821	57°·55	August
1797	58·83	July	1820	57·3	July
1833	58·87	July	1841	57·30	August
1843	58·78	July	1799	57·05	July
1839	58·63	July	1849	57·01	August
1827	58·45	July	1844	56·89	July
1814	58·4	July	1845	56·81	June
1810	58·3	August	1829	56·55	July
1811	58·2	July	1823	56·40	July
1813	58·0	July	1817	56·3	July
1830	57·72	July	1812	56·1	August
1832	57·71	July	1836	56·00	July
1809	57·7	July	1816	54·8	July
1828	57·63	July			
1815	57·6	July	Mean of the whole, 58°·91		

From whence it appears, that in 56 years June was five times the hottest month, July thirty-six times, and August fifteen times.*

39. If we make a similar comparison for the coldest month of the year, we shall find it to range over no less than five calendar months from November to March. In the following Table it is to be observed, that when November or December is set down as the coldest month, it means that it was colder than the immediately *succeeding* January, February, or March. [In Tables III. and IX. the monthly ranges are those strictly included within the year.]

TABLE V.—CONTAINING THE MEAN TEMPERATURE OF THE COLDEST MONTHS OF EACH WINTER.

1814	27°·7	January	1843	34°·28	February
1838	29·82	February	1799–1800	34·30	December
1795	30·03	January	1830	34·32	January
1796–7	31·03	December	1846–7	34·39	December
1823	31·06	January	1831	34·69	January
1809	31·1	January	1833	34·69	January
1850	31·50	January	1837	34·78	March
1820	31·6	January	1799	34·87	February
1829	32·08	January	1842	34·98	January
1801–2	32·53	December	1806	35·0	January
1844–5	32·98	December	1800–1	35·12	December
1826	33·19	January	1803	35·19	January
1815	33·4	January	1804	35·22	February
1841	33·43	January	1812–13	35·3	December
1848	33·64	January	1816–17	35·4	December
1827	33·98	February	1817–18	35·4	December
1807–8	34·1	November	1812	35·5	January
1811	34·1	January	1839	35·50	January
1815–6	34.1	December	1804–5	35·68	December

* Reducing Mr GLAISHER's numbers for Greenwich in proportion to the number of years, they would give—June $3\frac{1}{4}$, July 33, August $17\frac{1}{2}$, September 2. The maximum occurs, therefore, later at Greenwich that at Edinburgh.

TABLE V. (*continued.*)

1844	35·77	February	1795–6	37·80	November
1810	36·1	February	1835	37·88	January
1819	36·6	February	1821	38·29	January
1807	36·8	Feb. and March	1824–5	38·42	December
{ 1798	37·09	January	1845–6	38·77	December
{ 1849	37·09	January	1822	39·05	January
1836	37·15	February	1832	39·13	January
1823–4	37·32	December	1828	39·45	January
1840	37·47	February	1833–4	40·30	December

40. Thus it appears that out of fifty-six winters, the lowest monthly mean temperature occurred twenty-seven times in January, fifteen times in December, ten and a half times* in February, twice in November (in 1795 and 1807), and one and a half times in March (in 1807 and 1837).†

41. III. *The Epoch of Highest Temperature* mainly determines the earliness or lateness of the season. It is well known that in these latitudes the mean epochs of greatest heat and cold are, on a long average of years, nearly six months apart.‡ But in any given year, the fluctuations of temperature in winter are so irregular, as to make it very difficult to define the inferior culmination of the curve of temperature. I employ, therefore, the position of the maximum, as deciding the character of the season with respect to earliness or lateness. This has been approximately determined by a very simple process of approximation, which I used in my paper on the Temperature of the Earth at Different Depths.§ The rule is as follows:—"Calling A the excess of the mean temperature of the hottest month above the *preceding* month, B the excess of the mean temperature of the hottest above the *following* month; Then $15 \times \frac{A-B}{A+B}$ is the number of days $\pm$ that the hottest day of the year $\left\{\begin{smallmatrix}\text{follows}\\ \text{precedes}\end{smallmatrix}\right.$ the 15th day of the hottest month."

42. The results of this (merely approximate) estimate will be given in a future table (see Table IX. col. 5, below). In the meantime, the following is the classification of the seasons, as early or late. The earliest date was June 22d in 1845, the latest August 14th in 1795.

* When the temperature of February and March was the same, as in 1807, then one-half is the proportion for each.

† Mr GLAISHER's numbers for Greenwich would give for a like number of years, January 30, December 15, February 10, March 1, November 0.

‡ See QUETELET on the Climate of Brussels, and § 6 of the present paper.

§ Edin. Trans., vol. xvi. p. 216.

TABLE VI.—THE SEASONS ARRANGED AS EARLY OR LATE BY THE DATE OF SUMMER MAXIMUM.

1.	1845*	8.	1818	15.	1817	22.	1808	29.	1797	36.	1815	43.	1849	50.	1796
2.	1846*	9.	1850	16.	1824	23.	1799	30.	1807	37.	1816	44.	1831	51.	1810
3.	1798	10.	1826	17.	1828	24.	1803	31.	1834	38.	1823	45.	1812	52.	1821
4.	1822	11.	1827	18.	1830	25.	1811	32.	1809	39.	1832	46.	1835	53.	1801
5.	1804	12.	1833	19.	1839	26.	1813	33.	1814	40.	1843	47.	1841	54.	1802
6.	1836	13.	1837	20.	1844	27.	1838	34.	1825	41.	1805	48.	1819	55.	1842
7.	1829	14.	1848	21.	1847	28.	1820	35.	1800	42.	1806	49.	1840	56.	1795

SECT. 4. *On the Annual and Monthly Fall of Rain at Edinburgh for Thirty-eight years.*

43. Mr ADIE appears always to have paid great attention to the amount of rain.

44. The rain-gauge used by him was a metal funnel, about 6½ feet above the ground, with a glass tube connected with it, and a stop-cock, by means of which the depth of rain was at once indicated.†

45. The following Table contains the monthly results for thirty-eight complete years, and part of two others. I have been unable to find a comparable register for the years omitted; but even had one existed for a neighbouring locality, the seemingly capricious variations of this element of climate would make it hazardous to attempt any arbitrary reduction from one spot to another:—

* In these two years, and also in 1810, there is some ambiguity owing to a double maximum occurring in June and August. In 1845 and 1846, at least, the effective maxima must be held to have occurred in July.

† Mr ALEXANDER J. ADIE has favoured me with the following information about his father's rain-gauges :—" *Linlithgow, 14th March* 1859.—My belief is, that there were but two gauges used in all the time the register was kept, and that the one still standing in the garden at Canaan Cottage was the only one used after that at Merchant Court was broken up. The second gauge is about 6½ feet above the ground, and of the ordinary form of the funnel mouth, with the glass tube and scale at the side. Falls of snow were taken by pushing down a cylinder through the snow in an open place, melting it, and measuring the depth of water for the fall had it been in rain."

TABLE VII.—MONTHLY FALL OF RAIN AT EDINBURGH.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Year.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1795	2·81	3·87	1·37	3·01	1·20	3·92	2·42	3·62	1·12	4·87	4·58	3·81	36·60
1796	3·28	1·40	·43	1·09	1·43	1·03	2·77	·45	2·21	1·19	1·31	1·06	17·65
1797	1·32	·67	1·20	1·47	1·96	2·18	5·19	4·50	2·99	3·24	1·20	1·26	27·18
1798	1·80	·55	1·52	1·56	1·62	2·53	2·10	2·99	2·28	2·15	2·07	1·41	22·58
1799	·89	1·57	·47	2·15	3·27	·87	2·60	5·66	4·02	1·99	1·79	1·23	26·51
1800	3·26	·49	1·34	2·05	2·50	·53	·40	1·26	2·53	3·33	·98	2·91	21·58
1801	1·75	1·44	·82	·60	1·99	·20	5·25	·88	2·66	1·59	1·06	2·17	20·41
1802	·71	1·87	·69	·73	·86	2·21	4·19	2·13	2·37	2·43	2·09	1·02	21·30
1803	·80	1·56	·74	1·16	1·13	1·35	·86	2·00	1·82	1·00	2·26	1·13	15·81
1804	3·72	·57	2·58	2·04	1·58	1·32	1·86	3·91	·74	2·37	1·92	1·96	24·57
1805	·65	1·58	……	·64	1·01	1·38	……	2·83	……	……	……	……	……
1822	1·23	2·50	3·57	1·41	1·80	1·36	4·53	2·36	1·27	2·39	2·12	1·60	26·14
1823	2·23	3·85	·66	1·68	2·35	1·	4·25	3·87	1·82	3·10	1·07	4·38	30·26
1824	·87	1·70	1·34	·57	·63	2·01	1·58	1·50	1·62	4·73	4·38	3·88	24·81
1825	1·31	·69	·43	1·41	3·25	2·05	·15	1·89	2·85	2·19	3·91	1·99	22·12
1826	·55	1·77	1·33	1·52	1·25	·30	2·31	1·83	1·01	1·38	·76	1·26	15·27
1827	3·33	1·58	4·84	2·74	1·28	1·62	2·27	4·89	1·15	4·97	1·02	2·90	32·59
1828	1·70	·98	1·18	1·42	1·85	·81	4·57	3·43	2·31	·86	3·94	2·18	25·23
1829	2·49	1·61	·32	3·35	·77	2·03	4·48	6·80	1·77	2·53	2·48	1·33	29·96
1830	·95	1·21	1·78	2·28	1·96	2·54	6·57	6·69	3·63	·16	3·13	2·35	33·25
1831	·66	3·88	1·97	1·54	·69	1·41	2·44	4·03	1·55	2·15	2·95	1·26	24·53
1832	·61	1·42	1·29	1·21	1·35	2·89	1·14	3·64	·92	5·53	·95	2·28	23·23
1833	·57	2·53	1·43	1·34	·79	3·48	1·53	1·16	2·37	1·13	·71	3·84	20·88
1834	3·28	·86	1·65	·44	·51	1·45	3·20	1·18	4·50	1·23	1·22	1·52	21·04
1835	1·08	2·48	2·28	·79	2·04	1·02	1·37	1·99	5·43	2·09	2·76	1·89	25·22
1836	4·06	1·62	3·79	1·54	·56	2·50	6·53	2·45	2·81	1·66	3·05	2·46	33·03
1837	1·23	2·14	1·28	1·61	1·53	2·86	4·54	4·13	1·73	2·02	2·03	1·67	26·77
1838	2·47	1·21	2·76	1·78	2·90	5·16	2·45	2·97	4·00	1·55	3·06	·73	31·04
1839	1·76	1·45	1·47	·33	·47	3·91	3·51	1·77	3·09	2·38	1·65	1·66	23·45
1840	3·72	1·58	·43	·19	3·97	2·75	3·46	1·99	2·39	2·01	2·33	·68	25·50
1841	1·23	1·64	·60	1·14	1·14	1·56	3·87	3·64	2·63	4·53	2·28	1·96	26·22
1842	1·01	1·11	3·44	·15	1·45	·97	1·53	1·36	1·45	·98	1·63	1·79	16·87
1843	1·69	1·38	·99	1·87	2·99	2·26	3·59	1·40	·89	4·20	2·20	·34	23·80
1844	1·23	1·72	2·42	·40	·15	2·71	2·39	2·11	2·70	·82	3·92	·37	20·94
1845	1·77	·61	1·67	·40	2·24	3·08	1·72	3·48	1·77	6·14	1·70	2·04	26·62
1846	2·64	1·60	·97	2·88	1·27	3·59	4·17	5·01	3·35	3·60	1·74	·72	31·54
1847	·51	·79	·13	1·25	4·77	1·79	1·37	·91	1·25	3·48	1·64	4·88	22·77
1848	1·26	5·21	2·80	1·06	·60	6·04	1·36	2·00	1·45	4·56	2·42	1·84	30·60
1849	2·84	·97	1·05	1·64	1·66	2·45	2·58	2·31	2·02	1·74	1·50	1·45	22·21
1850	1·62	2·84	·14	·88	3·14	1·18	1·63	2·20	1·83	……	……	……	……
Means,	1·77	1·71	1·51	1·38	1·69	2·10	2·89	2·83	2·26	2·58	2·15	1·92	25·00*
	TOTAL, 24·79.												

* For 38 *complete* years.

46. The average rain-fall at Edinburgh is therefore exactly 25 inches, ranging from 36·60 in 1795 to 15·27 in 1826. The order of the seasons from Wet to Dry is shown in the following Table for the years which are complete :—

TABLE VIII.—THE SEASONS ARRANGED FROM WET TO DRY.

1.	1795	8.	1823	15.	1822	22.	1843	29.	1800	36.	1842	The years are from 1795–1804, and from 1822–1849 inclusive.
2.	1830	9.	1829	16.	1840	23.	1839	30.	1802	37.	1803	
3.	1836	10.	1797	17.	1828	24.	1832	31.	1834	38.	1826	
4.	1827	11.	1837	18.	1835	25.	1847	32.	1844	...	...	
5.	1846	12.	1845	19.	1824	26.	1798	33.	1833	...	...	
6.	1838	13.	1799	20.	1804	27.	1849	34.	1801	...	...	
7.	1848	14.	1841	21.	1831	28.	1825	35.	1796	...	...	

47. The means of the columns of Table VII. show the following averages of rain-fall according to the season :—

WINTER.	Inch.	Inch.	SPRING.	Inch.	Inch.	SUMMER.	Inch.	Inch.	AUTUMN.	Inch.	Inch.
Dec.	1·92	5·40, or	Mar.	1·51	4·58, or	June,	2·10	7·82, or	Sept.	2·26	6·99, or
Jan.	1·77	21·8 per	April,	1·38	18·4 per	July,	2·89	31·6 per	Oct.	2·58	28·2 per
Feb.	1·71	cent.	May,	1·69	cent.	Aug.	2·83	cent.	Nov.	2·15	cent.*

48. It thus appears that at Edinburgh spring is decidedly the driest, and summer decidedly the wettest, quarter of the year. If we project the monthly results, we obtain a pretty regular curve, showing a minimum about the middle of April, and a maximum about the end of July, but October has a slight maximum of its own. Of individual rainfalls, Mr ADIE noted, on the 18th November 1795, 2·89 inches within 24 hours; on the 30th July 1797, 2·63 inches; and on the 18th August 1797, 2·56 inches, nearly the whole of which fell within 6 hours from 2 to 8 P.M.

SECT. 5. *General Remarks on the Succession of the Seasons for the period* 1796–1850 *and their Extremes.*

49. The following Table contains a concise view of the succession of the seasons from 1795 to 1850. It is difficult to trace any periodic recurrence of good and bad seasons, although it is very plain that they happen for the most part in groups of usually from seven to ten or twelve years' duration.† This is well seen by the third column of Table IX., showing the annual deviations of the

* The sum total at all seasons is 24·79 inches, which is slightly below the average of 38 *complete* years given above. This arises from the partial observations of 1805 and 1850 (which are below the average) being included in the monthly means.

† There is a slight appearance (from Table IX. column 2) of alternate ten-year periods below and above the mean, commencing in 1793 or 1794, and terminating in 1852 or 1853,—

The maxima would be 1809, 1829, 1849.
The minima would be 1799, 1819, 1839.

mean temperature from the average of fifty-six years. The succeeding columns show, *First*, the range of the monthly means within one and the same year. *Secondly*, the approximate date of the maximum temperature of summer, deduced from the monthly means, on which some remarks have already been made in Art. 41. *Thirdly*, the highest and lowest *mean temperature of any day* in each year, with the dates (the Dunfermline observations not included). *Fourthly*, the *extreme* temperatures occurring in any year, with the dates (confined to the period for which self-registering instruments were used). The highest individual temperature noted in the twenty-eight years 1822–1850, was 87°, on the 24th and 26th June 1826, and on the 17th June 1839; and the lowest, 5°, occurred on the 31st January 1845 and the 29th January 1848.

50. It will easily be seen that the second, fourth, and fifth columns afford the means of supplying the approximate constants for the curve of each year denoted by A, B, and u_1, in the note to Art. 35, and in § 6, below. It might be wished that these constants were compared in several moderately distant localities (for example over Europe), to see how far the characteristic features of any season may be held to extend. By this means it might even be possible, after ascertaining the proportional constants for each season, to infer the characters of the climate of any locality from a few years' observation only. Even were this method applicable to so limited an area as that of Great Britain, it might be of great use in generalizing meteorological results.

TABLE IX.—Showing the General and Extreme Characters of each Season.

Year.	Mean Temp.	Deviation from the Mean.	Diff. Hottest and Coldest Months.	Calculated Time of greatest Heat.†	Highest Mean Daily Temp.	Date.	Lowest Mean Temp.	Date.	Difference or Range.	Extreme Heat.	Date.	Extreme Cold.	Date.	Extreme Range.
	°	°	°		°		°		°	°		°		°
1795	45·67	−1·08	29·16	Aug. 14	68·5	Aug. 12 ...	16·5	Jan. 29	52·	...	....	...	....	.....
1796	46·46	−0·29	28·14	Aug. 10	68·	June 30 ...	18·5	Dec. 24	49·5	...	....	...	....	.....
1797	46·33	−0·42	20·38	July 22	67·5	July 14 ...	24·	Nov. 29	43·5	...	....	...	....	.....
1798	47·59	+0·84	25·64	June 25	69·	June 28 ...	21·5	Dec. 28	47·5	...	....	...	....	.....
1799	44·44	−2·31	22·75	July 19	67·	June 21, 22	20·	Dec. 31	47·	...	....	...	....	.....
1800	45·70	−1·05	26·19	July 24	70·	July 24 ...	23·	Dec. 30	47·	...	....	...	....	.....
1801	46·67	−0·08	27·68	Aug. 13	69·	Aug. 19 ...	25·	Dec. 19	44·	...	....	...	....	.....
1802	46·86	+0·09	23·15	Aug. 13	67·	Aug. 17 ...	24·5	Jan. 1, 6, 7	42·5	...	....	...	....	.....
1803	46·63	−0·12	27·55	July 19	77·	July 18 ...	19·5	Jan. 13	57·5	...	....	...	....	.....
1804	47·31	+0·56	24·04	June 28	66·	Sept. 14 ...	21·	Feb. 7, D^{c} 31	45·	...	....	...	....	.....
1805	47·41	+0·66	24·1	July 30	......	....	......	....	......	...	....	...	....	.....
1806	48·26	+1·51	23·9	Aug. 1	......	....	......	....	......	...	....	...	....	.....
1807	45·82	−0·93	27·8	July 22	......	....	......	....	......	...	....	...	....	.....
1808	46·91	+0·16	27·0	July 18	......	....	......	....	......	...	....	...	....	.....
1809	46·80	+0·05	26·6	July 23	......	....	......	....	......	...	....	...	....	.....
1810	46·26	−0·49	22·5	Aug. 10	......	....	......	....	......	...	....	...	....	.....
1811	47·00	+0·25	24·1	July 19	......	....	......	....	......	...	....	...	....	.....
1812	45·32	−1·43	20·8	Aug. 6	......	....	......	....	......	...	....	...	....	.....
1813	46·48	−0·27	22·1	July 20	......	....	......	....	......	...	....	...	....	.....
1814	45·21	−1·54	30·7	July 23	......	....	......	....	......	...	....	...	....	.....
1815	46·40	−0·35	24·2	July 24	......	....	......	....	......	...	....	...	....	.....
1816	44·46	−2·29	19·6	July 25	......	....	......	....	......	...	....	...	....	.....
1817	45·69	−1·06	20·9	July 15	......	....	......	....	......	...	....	...	....	.....
1818	47·42	+0·67	23·2	July 5	......	....	......	....	......	...	....	...	....	.....
1819	46·27	−0·48	27·7	Aug. 9	......	....	......	....	......	...	....	...	....	.....
1820	46·11	−0·64	25·7	July 21	......	....	......	....	......	...	....	...	....	.....
1821	47·44	+0·69	19·26	Aug. 11	67·5	July 19 ...	17·	Jan. 3	50·5	...	....	...	....	.....
1822	47·82	+1·07	23·11	June 26	65·5	June 5 ...	25·	Dec. 28, 29	40·5	80	June 13 ...	18	Dec. 28	62
1823	45·30	−1·45	25·34	July 25	66·	Aug. 11 ...	19·	Feb. 5	47·	75	Aug. 11 ...	11	Feb. 5	64
1824	47·26	+0·51	21·47	July 16	72·	Sept. 2 ...	22·5	Dec. 5	49·5	85	Sept. 2 ...	16	Dec. 5	69
1825	48·19	+1·44	23·43	July 23	70·5	July 14 ...	27·	Jan. 5, F^{b} 4	43·5	83	July 30, 31	19	Nov. 10	64
1826	48·66	+1·91	28·79	July 12	74·	June 28 ...	18·	Jan. 16	56·	87	June 24, 26	10	Jan. 16	77
1827	47·11	+0·36	24·47	July 12	63·5	J^{y} 16, S^{t} 16	19·	Jan. 3	44·5	77	July 16 ...	14	Jan. 3	63
1828	48·46	+1·71	18·18	July 16	66·	June 27 ...	23·	Jan. 11	43·	76	Aug. 27 ...	15	Jan. 11	61
1829	45·23	−1·52	24·47	July 3	65·	Aug. 8 ...	22·5	Jan. 22	42·5	75	July 13 ...	15	Jan. 22, 25	60
1830	45·98	−0·77	23·40	July 16	68·	July 26 ...	22·	Dec. 24	46·	81	July 28 ...	15	Dec. 25, 26	66
1831	47·48	+0·73	25·41	Aug. 3	67·	July 29, 31	26·	Feb. 4	41·	76	July 31 ...	19	Feb. 4	57
1832	47·72	+0·97	18·58	July 25	65·	Aug. 10 ...	29·5	Jan. 3, 27	35·5	75	Aug. 10 ...	24	Jan. 27	51
1833	47·19	+0·44	24·18	July 13	67·5	July 28 ...	27·	Jan. 15	40·5	75	July 17, 29	23	Jan. 16	52
1834	48·74	+1·99	18·76	July 22	68·5	Aug. 12 ...	31·	F^{b} 21, N^{v} 24	37·5	77	Aug. 12 ...	20	Mar. 24	57
1835	46·80	+0·05	21·21	Aug. 6	66·5	Aug. 11 ...	28·	Jan. 20	38·5	77	Aug. 4, 10	22	Jan. 21	55
1836	45·73	−1·02	17·91	July 2	65·	June 15 ...	28·	Dec. 26	37·	76	June 15 ...	24	Jan. 19	52
1837	45·72	−1·03	24·64	July 14	64·	July 6 ...	23·	Jan. 11	41·	73	July 10 ...	16	Jan. 12	57
1838	44·72	−2·03	29·33	July 20	68·5	July 12 ...	18·	Jan. 21	50·5	84	Sept. 9 ...	13	Feb. 13	71
1839	46·36	−0·39	23·13	July 17	66·5	June 17 ...	24·	Feb. 21	42·5	87	June 17 ...	13	Jan. 30	74
1840	46·72	−0·03	22·56	Aug. 9	67·5	Aug. 21 ...	27·5	Dec. 24	40·	78	Aug. 9 ...	21	J^{n} 30, F^{b} 27	57
1841	46·63	−0·12	23·87	Aug. 7	67·	Aug. 20 ...	21·5	Jan. 9	45·5	79	June 10 ...	8	Jan. 9	71
1842	47·96	+1·21	24·95	Aug. 13	68· ?	Aug. 13 ? ...	26·5	Jan. 16	41·5	79	July 23 ...	18	Jan. 16, 17	61
1843	47·62	+0·87	24·50	July 26	67·	July 14 ...	24·	Feb. 15	43·	77	July 14 ...	16	Feb. 15, 17	61
1844	46·73	−0·02	23·91	July 17	66·	July 22, 25	24·5	Feb. 21	41·5	77	Sept. 1 ...	13	Feb. 27	64
1845	46·27	−0·48	21·60	June 22‡	69·	June 12 ...	18·	Jan. 31	51·	79	June 12, 13	5	Jan. 31	74
1846	49·60	+2·85	27·21	June 24‡	71·5	June 5 ...	25·5	Dec. 25	46·	84	June 5 ...	16	Dec. 18	68
1847	47·39	+0·64	25·93	July 17	75·5	July 12 ...	25·5	F^{b} 8, 9, D^{c} 31	50·	83	July 14 ...	17	Feb. 8, 9	66
1848	47·00	+0·25	25·54	July 14	68·5	July 13 ...	17·5	Jan. 29	51·	82	July 13 ...	5	Jan. 29	77
1849	46·51	−0·24	20·37	Aug. 2	65·5?	July 10 ? ...	20·	Jan. 2	45·5?	78	June 5 ...	19	Jan. 4, 6...	59
1850	47·02*	+0·27	27·61?	July 7	68·5	June 24 ...	19·5	Jan. 17	49·	78	July 23 ...	12	Jan. 18	66
Mean,	46·75	......	24·08		68·0	July 19·5	22·8	Jan. 11·9	45·2					

* Three months of 1850 are supplied from the general average of those months.

† Calculated by Formula of Art. 41.

‡ See Note to Table VI.

51. Table X. shows the succession of the seasons in a somewhat different form: the seasons being indicated as *Hot or Cold, Extreme or not, Summer Hot or Cold, Early or Late, Rainy or Dry.* The numbers affixed to any year, denote its Rank in those respects amongst all the years for which the observations were made. They are in fact the numbers in the Tables II., III., IV., VI., and VIII., arranged chronologically instead of quantitatively. The seventh column refers to the Price of Grain, which is considered in the concluding section of the present paper.

TABLE X.—Showing the Relative Characters of Fifty-six Successive Seasons in Chronological Order.

	Hot or Cold.	Summer, Hot or Cold.	Extreme or not.	Early or Late.	Rainy or Dry.	Oats, Cheap or Dear.		Hot or Cold.	Summer, Hot or Cold.	Extreme or not.	Early or Late.	Rainy or Dry.	Oats, Cheap or Dear.
1795	49	22	3	56	1	36	1823	51	52	20	38	8	38·5
1796	35	24	5	50	35	10	1824	18	15	45	16	19	28
1797	38	30	49	29	10	3	1825	6	8	34	33	28	32
1798	11	9	17	3	26	5	1826	3	3	4	10·5	38	48
1799	56	47	40	24	13	52	1827	20	34	24·5	10·5	4	24
1800	47	10	14	35·5	29	55	1828	4	42	55	17	17	34
1801	30	12	8	54	34	23	1829	52	51	24·5	7	9	21·5
1802	25	16	37	54	30	17	1830	43	39	35	18	2	38·5
1803	31·5*	2	10	24	37	26	1831	12	13	19	44	21	26
1804	17	19·5	30	5	20	34	1832	9	40	54	38	24	6
1805	15	11	28·5	41	...	...	1833	19	31	27	12	33	3
1806	5	29	32	42	...	38·5	1834	2	19·5	53	31	31	14
1807	44	4	6	30	...	51	1835	26·5	28	46	45·5	18	14
1808	24	1	12	22	...	47	1836	45	56	56	6	3	41
1809	26·5	41	13	33	...	53	1837	46	18	22	13·5	11	18
1810	41	36	42	51	...	29	1838	54	25	8	26·5	6	42
1811	22·5	37	28·5	24	...	45	1839	37	33	38	19	23	34
1812	50	54	48	45·5	...	54	1840	29	26	41	48·5	16	11·5
1813	34	38	43	26·5	...	43	1841	31·5	45·5	33	47	14	11·5
1814	53	35	1	33	...	31	1842	7	14	21	54	36	8
1815	36	43	26	35·5	...	7	1843	10	32	23	40	22	19
1816	55	56	51	38	...	49	1844	28	49	31	20	32	21·5
1817	48	53	47	15	...	45	1845	39·5	50	44	1†	12	38·5
1818	14	17	36	8	...	45	1846	1	7	11	2†	5	50
1819	39·5	6	7	48·5	...	26	1847	16	5	15	21	25	30
1820	42	45·5	16	28	...	20	1848	22·5	23	18	13·5	7	9
1821	13	44	52	52	...	16	1849	33	48	50	43	27	1
1822	8	21	39	4	15	14	1850	21	27	9	9	...	3

* When in this and the following columns two years are designated by the same number (whether whole or fractional), it indicates that they were *equally* hot, or extreme, or rainy (as the case may be), and the mean of the numbers is assigned to them which they would have had if there had been an inequality.

† These positions are not the true ones, for the reason assigned in the Note to Table VI. In both years, however, the actual highest temperature, both in the extremes and in the mean of the day and of the month, occurred in June.

SECTION 6. *On the Form of the Annual Curve of Temperature at Edinburgh, and on its Accidental Fluctuations.*

52. The method usually employed to represent the annual curve of temperature, is to take the mean temperature of the twelve separate months (each month being represented in extent by 30° or one-twelfth of an entire circumference), and to express them by a series of the form—

$$y_n = A + B \sin (30^\circ \times n + u_1), + C \sin (30^\circ \times 2n + u_2) + D (30^\circ \times 3n + u_3), + \&c.$$

Where y_n is the temperature of any month whose number is n (reckoning January=0, February=1, &c.) Eliminating the constants (by the method given, for example, in DOVE'S *Repertorium*, vol. ii. p. 275, or "Encyclopædia Britannica" (8th Edition), Art. *Meteorology*, p. 665, we obtain the following numerical formula:—

$$y_n = 46^\circ{\cdot}88 - 10^\circ{\cdot}83 \sin (30n + 83^\circ\ 28') + 0^\circ{\cdot}963\ (60n + 52^\circ\ 8'), + \&c.$$

(the fourth term is negligible, its greatest value being only 0°·104).

53. A comparison of this calculation with the observations collected in Table I. gives the following results:—

TABLE XI.

Month.	Temperature. Observed.	Temperature. Calculated.	Excess of Calculation.	Month.	Temperature. Observed.	Temperature. Calculated.	Excess of Calculation.
	°	°	°		°	°	°
January,.....	36·64	36·88	+0·24	July,.........	58·29	58·40	+0·11
February,....	37·92	37·84	−0·08	August,.......	57·49	57·70	+0·21
March,.......	40·58	40·53	−0·05	September,..	53·72	53·46	−0·26
April,.......	44·84	44·89	+0·05	October,......	47·49	47·35	−0·14
May,.........	50·26	50·30	+0·04	November,...	41·17	41·68	+0·51
June,........	55·65	55·45	−0·20	December,...	38·57	38·05	−0·52

54. Consequently, the mean temperatures *of the months* are satisfactorily represented by the formula. It is evident, however, that the annual curve drawn through the mean temperatures of the months will lie somewhat too low during the hotter part of the year, and too high in winter; in other words, the inflection of the curve will be too small. This arises from the fact that the *mean elevation* of a given number of points, which all coincide with the arc of a curve, will necessarily fall *within* the concavity of the curve, and the true curve will be external to the curve of the means, especially if the period embraced in the means be so considerable as thirty days.

55. The correction for this (which, I think, has not usually been made) is easily found, with sufficient approximation, as shown in the subjoined note.*

* Let A B C D be four points in the *true* annual curve which is sought, and which is assumed to be symmetrical on either side. It will be sufficient for a first approximation to assume that these points, so far as they are considered at one time, are situated in a parabolic arc, formed by daily temperatures horizontally equidistant from one another. The mean temperature of the month BC (for example) will lie at β, and not at b in the parabolic arc. In like manner α and γ are the tabular averages for the preceding and following months. We want to find the quantity $\beta\, b$, by

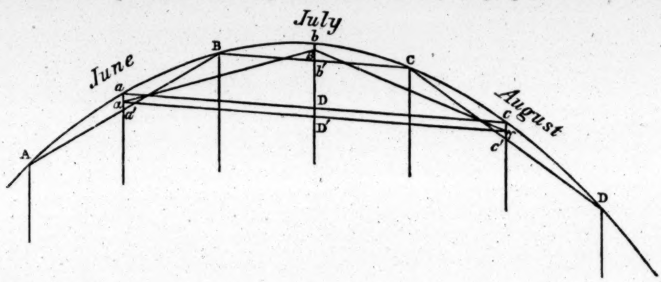
56. The greatest value of this correction of the numbers in the preceding table, in order to obtain the curve of daily mean temperature, is about $0^\circ \cdot 15$. As it will only be sensible in the second term of the equation of the annual curve, and as it tends to increase its co-efficient, this latter, instead of $10^\circ \cdot 83$, becomes $10^\circ \cdot 98$; and if we farther modify the angular constants of Art. 52, so as to adapt them to the beginning of the year as an origin, instead of the middle of January, the formula becomes (x being the distance of any day of the year from the beginning, in angular measure)—

$$y = 46^\circ \cdot 88 - 10^\circ \cdot 98 \sin (x + 68^\circ 28') + 0^\circ \cdot 96 \sin (2x + 22^\circ).$$

57. If we consider the two first terms only of this formula, the hottest day will be the 23d July; if all three terms, it will be the 27th July. The coldest day in the former case would be the 22d January, or in the latter, the 17th January. The effect of the third term is therefore to shorten the period of declining temperature by about six days, and to increase the period of rise by the same quantity. The days corresponding to the mean temperature of the year shown by the geometric curve are the 28th April and the 18th October. The temperature is therefore above the mean for 173 days, and below it for 182 days.

58. We next proceed to compare this equation with the annual curve in detail, as derived from Mr ADIE's forty years' observations.

which the monthly mean is to be increased, in order to make it coincide with the temperature of the middle day of the month. β is the centre of gravity of the daily temperatures lying in the arc BC. Considering these daily temperatures as equally heavy points distributed uniformly with respect to a double ordinate BC parallel to the tangent at b, we have by the properties of the centre of gravity



$$\beta b = \frac{\int p \cdot \frac{y^2}{2a} dy}{\int p \cdot dy};$$ where the equation to the parabola is $y^2 = 2ax$, and where the weight of an individual observation is p. Hence we have $\beta b = \frac{y^2}{6a} = \frac{x}{3}$, where x is the abscissa $b\,b'$ intercepted by the chord or double ordinate BC. In like manner $\alpha a = \frac{1}{3} a a'$ and $\gamma c = \frac{1}{3} c c'$. But a, c, the points representing the middle of the preceding and following months, are 60 days apart, while B and C are only 30 days apart. Therefore $b\text{D} = 4bb'$ and $\beta b = \frac{1}{12} b\text{D}$, which is equal (neglecting small quantities) to very nearly $\frac{1}{12}\beta\text{D}'$. So that the required correction is found by *increasing* the co-ordinate of temperature expressed by the periodic part of the equation in the text (+ or − as the case may be) at the middle day of each month by $\frac{1}{12}$ *of the difference between the mean temperature of the month and the average of the temperatures of the preceding and following months.*

TABLE XII.—SHOWING THE MEAN TEMPERATURE FOR EVERY DAY OF THE YEAR AT EDINBURGH, DERIVED FROM FORTY YEARS' OBSERVATIONS; ALSO FOR EACH OF FOUR DECENNIAL PERIODS; ALSO THE FLUCTUATION IN THE MEAN TEMPERATURE OF EACH DAY IN FORTY YEARS.

JANUARY.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1805,	34·0	34·9	36·4	39·2	38·5	37·0	36·0	35·7	36·5	35·2	34·7	35·2	37·4	37·1	37·2	39·8	39·6	39·1	39·7	39·7	38·4	37·9	38·0	37·4	36·7	38·2	36·0	36·3	35·7	37·8	35·0
1821—1830,	36·1	34·4	33·1	35·2	33·7	35·8	36·7	35·9	35·5	36·1	34·2	35·3	35·9	35·6	32·7	34·0	34·2	38·1	37·3	36·9	38·8	35·3	35·1	36·3	36·2	37·0	36·8	37·9	39·0	41·1	40·9
1831—1840,	37·5	37·6	38·6	38·4	37·4	36·6	36·4	36·9	36·1	34·4	35·0	35·8	37·3	36·4	34·6	35·5	35·7	37·3	36·8	36·2	36·0	37·5	39·7	39·1	37·9	36·7	36·1	36·3	34·6	34·1	35·5
1841—1850,	36·6	33·9	35·7	36·9	37·2	36·0	35·5	35·3	33·5	35·3	35·3	35·4	34·7	35·0	34·0	35·1	35·1	37·0	38·3	35·4	36·1	37·3	39·6	39·7	39·7	40·3	38·7	39·2	36·9	37·7	36·2
MEAN,	36·10	35·24	35·99	37·46	36·72	36·37	36·17	35·96	35·42	35·26	34·80	35·46	36·36	36·06	37·15	36·14	36·15	37·91	38·05	37·05	37·34	37·01	38·12	38·15	37·64	38·07	36·92	37·45	36·57	37·69	36·94
Highest M. T. in 40 yrs.,	46·0	44·5	46·0	47·5	47·0	48·0	47·5	50·0	50·0	49·5	47·5	48·0	49·0	52·0	47·0	49·0	50·5	49·0	49·5	50·0	50·5	49·0	48·5	49·5	49·0	49·0	48·0	50·0	48·5	56·5	51·0
Lowest,	26·0	20·0	17·0	23·0	23·0	26·5	25·0	24·0	21·5	26·0	23·0	24·5	19·5	20·0	19·0	18·0	19·5	22·0	22·0	18·5	18·0	18·5	21·5	23·5	24·0	22·5	25·5	24·5	16·5	24·0	18·0
Fluctuation,	20·0	24·5	29·0	24·5	24·0	21·5	22·5	26·0	28·5	23·5	24·5	23·5	29·5	32·0	28·0	31·0	31·0	27·0	27·5	31·5	32·5	30·5	27·0	26·0	25·0	26·5	22·5	25·5	32·0	26·5	33·0

FEBRUARY.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	...	...
1795—1805,	36·4	37·7	36·7	35·2	35·1	34·1	33·5	37·6	38·9	39·0	37·0	35·2	34·6	35·3	35·4	35·3	34·0	35·0	37·9	38·0	37·9	39·9	39·7	39·3	38·1	37·6	37·6	35·8	33·8	...	...
1821—1830,	39·8	37·8	36·8	36·3	35·8	38·2	40·4	39·4	39·0	39·1	38·4	39·7	38·8	37·9	36·4	37·4	37·5	33·9	35·2	36·8	37·5	38·3	37·3	39·9	40·4	40·3	41·0	39·3	46·0	...	...
1831—1840,	35·8	36·0	37·0	37·3	39·3	38·9	40·0	40·5	40·5	39·5	39·5	39·2	38·0	39·6	40·1	40·8	38·9	39·3	36·9	36·1	33·4	36·4	38·1	37·4	36·3	35·0	36·2	37·2	37·6	...	...
1841—1850,	36·8	37·4	39·3	38·7	38·5	35·1	34·8	35·4	35·6	36·7	39·1	38·9	39·3	41·2	41·0	39·7	40·9	41·2	41·4	40·8	39·5	40·7	40·3	39·2	37·8	38·3	38·0	40·9	40·0	...	...
MEAN,	37·22	37·25	37·49	36·89	37·20	36·59	37·21	38·24	38·52	38·61	38·54	38·30	37·67	38·51	38·26	38·31	37·86	37·39	37·90	37·97	37·10	38·85	38·87	38·97	38·16	37·81	38·24	38·30	39·37	...	...
Highest M. T. in 40 yrs.,	52·5	50·0	51·0	50·5	51·0	50·0	49·0	47·0	49·0	51·5	49·5	48·0	48·0	49·5	49·5	50·5	47·5	48·5	54·0	47·5	48·0	50·0	53·5	53·0	52·5	52·5	52·5	55·0	51·5	...	...
Lowest,	22·0	26·0	25·0	24·0	19·0	23·0	21·0	23·5	25·5	28·5	25·5	23·5	19·5	19·0	24·0	24·5	24·0	25·0	26·0	28·0	24·0	25·0	27·0	32·0	30·0	29·0	27·5	21·0	31·0	...	...
Fluctuation,	30·5	24·0	26·0	26·5	32·0	27·0	28·0	23·5	23·5	23·0	24·0	24·5	28·5	30·5	25·5	26·0	23·5	23·5	28·0	19·5	24·0	25·0	26·5	21·0	22·5	23·5	25·0	34·0	20·5	...	...

MARCH.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1805,	37·1	36·3	37·6	36·8	35·8	35·7	35·9	38·9	38·8	37·9	37·5	37·1	38·9	38·7	38·2	38·9	39·8	38·8	38·3	38·0	39·2	40·3	40·0	41·9	42·3	42·1	42·0	41·3	40·5	39·7	43·2
1821—1830,	41·0	39·4	40·2	38·9	37·2	37·3	39·1	39·8	42·3	42·6	42·4	42·7	41·4	41·0	40·6	40·9	41·9	42·7	44·6	44·8	44·0	41·4	41·5	41·3	41·1	41·3	44·5	43·7	43·2	41·3	40·1
1831—1840,	38·4	39·7	40·4	41·1	39·8	38·6	37·9	37·5	38·9	39·9	40·2	39·4	40·6	40·7	40·4	40·0	39·0	40·5	41·6	42·0	42·2	40·4	39·4	36·5	38·1	37·9	42·2	40·9	40·3	40·8	41·9
1841—1850,	39·7	41·3	41·6	38·6	40·5	41·9	42·9	41·4	41·2	41·5	41·2	41·8	41·6	43·0	45·6	42·7	42·8	43·6	41·4	40·6	41·4	44·1	42·8	42·9	42·4	42·1	41·9	42·4	42·1	42·0	44·5
MEAN,	39·09	39·19	39·97	38·86	38·36	38·41	38·96	39·42	40·34	40·47	40·34	40·29	40·65	40·87	41·24	40·66	40·92	41·41	41·49	41·37	41·72	41·60	40·94	40·65	41·00	40·87	42·67	42·09	41·52	40·95	42·46
Highest M. T. in 40 yrs.,	51·0	50·0	51·0	52·5	47·0	48·5	50·5	51·0	53·5	62·0	49·0	51·0	53·0	52·0	56·0	53·5	53·0	55·0	52·5	52·0	51·0	50·5	51·0	51·5	53·0	54·0	52·0	51·0	57·5	48·5	52·0
Lowest,	26·0	26·0	31·0	29·0	27·5	28·0	25·5	27·0	28·0	31·0	31·0	28·0	28·5	28·5	29·0	25·0	32·5	32·5	29·0	30·0	32·5	33·0	31·5	31·0	32·0	30·5	30·5	30·5	29·5	29·0	30·5
Fluctuation,	25·0	24·0	20·0	23·5	19·5	20·5	25·0	24·0	25·5	31·0	18·0	23·0	24·5	23·5	27·0	28·5	20·5	22·5	23·5	22·0	18·5	17·5	19·5	20·5	21·0	23·5	21·5	20·5	28·0	19·5	21·5

APRIL.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	..
1795—1805,	42·9	43·2	41·3	41·9	40·9	41·7	43·9	44·4	43·6	43·7	43·0	43·4	44·5	46·7	47·3	45·9	45·8	45·9	45·8	45·1	45·3	46·0	45·7	45·1	46·2	47·2	47·5	46·7	45·7	47·7	...
1821—1830,	40·7	42·1	42·4	43·0	44·4	45·1	45·7	45·9	45·0	42·3	43·1	44·7	44·9	46·1	45·9	46·5	45·3	43·7	45·0	47·3	45·8	45·9	44·4	43·5	44·7	46·8	46·5	50·2	51·1	50·1	...
1831—1840,	40·8	42·0	40·1	42·1	44·3	43·4	42·5	41·7	42·1	43·1	42·0	44·4	43·7	44·2	45·2	42·8	42·4	42·3	43·9	44·9	44·8	46·4	46·2	45·4	46·4	47·2	46·9	46·4	45·0	45·5	...
1841—1850,	45·5	45·1	45·8	43·0	44·5	43·6	44·6	44·7	43·0	44·3	42·3	43·1	43·5	44·4	44·4	46·0	45·4	47·9	47·7	45·4	45·3	44·8	45·0	46·2	46·4	46·9	46·4	46·1	48·2	49·0	.
MEAN,	42·50	43·14	42·42	42·51	43·54	43·47	44·20	44·19	43·45	43·36	42·60	43·92	44·20	45·40	45·71	45·32	44·76	44·97	45·62	45·71	45·30	45·80	45·35	45·07	45·95	47·04	46·85	47·35	47·51	48·09	...
Highest M. T. in 40 yrs.,	51·0	52·0	54·5	53·0	52·0	52·0	53·0	53·5	57·0	59·0	57·5	56·0	52·5	54·0	56·0	53·0	52·0	53·5	55·5	57·0	56·5	57·0	58·0	57·5	56·5	56·0	57·0	58·5	59·0	58·5	...
Lowest,	31·5	26·5	31·5	31·0	30·5	33·5	34·5	34·5	34·5	34·0	33·5	30·0	35·5	36·0	37·5	33·5	28·5	33·0	36·5	34·5	33·0	34·0	34·0	33·0	37·0	39·0	37·0	38·0	37·5	38·5	...
Fluctuation,	19·5	25·5	23·0	22·0	21·5	18·5	18·5	19·0	22·5	25·0	24·0	26·0	17·0	18·0	18·5	19·5	23·5	20·5	19·0	22·5	23·5	23·0	24·0	24·5	19·5	17·0	20·0	20·5	21·5	20·0	...

MAY.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1805,	48·2	46·6	45·9	47·5	48·5	47·0	47·4	47·9	47·1	47·7	46·9	46·2	45·4	46·7	47·0	49·3	48·8	50·8	51·1	53·1	54·1	55·3	54·6	55·4	54·5	53·5	53·6	53·0	53·4	50·7	52.4
1821—1830,	50·1	50·0	48·5	49·0	50·3	49.7	49·6	50·0	48·3	48·5	48·2	48·2	49·4	48·9	51·2	51·3	52·6	51·9	50·7	49·6	50·5	50·4	52·3	51·1	51·6	50·3	52·2	51·9	52·5	54·9	55·0
1831—1840,	45.9	46·9	47·8	48·2	48·1	47·2	47·8	48·8	48·1	46·4	48·9	49·4	47·2	45·7	46·9	50·9	51·8	51·0	49·8	50·5	50·5	50·5	51·5	52·3	51·0	54·4	53·0	53·1	53·7	53·5	54·3
1841—1850,	49·7	48·1	49·4	47·5	47·6	47·6	49·2	47·8	47·2	49·0	49·7	49·9	52·6	51·9	51·2	51·3	49·6	49·2	49·4	50·6	50·7	51·8	51·6	53·9	52·6	52·4	53·1	52·1	53·5	54·6	54·0
MEAN,	48·50	47.91	47·91	48·06	48·65	47·91	48·52	48·65	47·71	47·92	48·45	48·45	48·66	48·32	49·10	50·74	50·71	50·75	50·27	50·99	51·50	52·01	52·52	53·20	52·45	52·67	53·01	52·54	53.29	53·45	53·92
Highest M. T. in 40 yrs.,	58·5	57·0	57·0	57·5	60·5	61·0	62·0	59·0	59·0	56·0	57·0	59·5	64·5	59·0	59·0	61·0	63·0	60·0	61·5	60·5	59·5	64·0	63·0	65·5	63·5	67·0	67·0	65·5	61·5	61·0	65·0
Lowest,	37·0	39·5	39·5	40·5	39·0	36·0	38·5	40·5	39·0	40·5	40·5	43·0	41·0	36·5	36·5	39·5	39·0	39·0	40·5	40·5	42·0	43·5	43·0	44·0	42·0	42·5	44·5	43·0	40·5	35·0	45·5
Fluctuation,	21·5	17·5	17·5	17·0	21·5	25·0	23·5	18·5	20·0	15·5	16·5	16·5	23·5	22·5	22·5	21·5	24·0	21·0	21·0	20·0	17·5	20·5	20·0	21·5	21·5	24·5	22·5	22·5	21·0	26·0	19·5

JUNE.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	...
1795—1805,	52·6	54·1	53·1	53·7	54·7	55·9	55·5	55·7	53·3	52·7	54·2	54·6	55·1	55·2	55·4	56·7	56·6	56·0	55·9	55·4	56·4	55·5	56·6	57·2	57·3	56·4	57·5	57·9	59·0	59·0	...
1821—1830,	55·9	54·8	54·4	54·0	52·3	51·7	56·0	54·9	56·0	55·4	57·2	59·2	58·7	57·1	54·6	54·8	55·5	56·3	53·2	55·9	54·1	55·2	57·2	57·6	57·7	57·9	57·3	59·0	59·5	57·4	...
1831—1840,	51·7	53·4	52·2	52·4	52·4	52·7	52·6	53·9	54·3	55·8	56·3	53·8	55·1	55·0	57·0	55·7	59·3	56·3	56·2	56·6	56·8	54·6	55·2	55·0	55·2	55·0	55·9	55·2	55·6	55·8	...
1841—1850,	54·3	55·8	55·7	56·5	56·9	56·8	54·5	53·8	53·9	56·6	54·6	54·5	56·4	55·5	55·5	54·3	54·0	56·3	56·1	56·7	59·9	58·2	57·9	55·5	54·4	55·2	57·0	57·4	55·2	56·4	...
MEAN,	53·65	54·54	53·89	54·16	54·11	54·30	54·66	54·59	54·41	55·14	55·59	55·52	56·34	55·80	55·89	56·15	56·36	56·22	55·37	56·17	56·81	55·90	56·75	56·34	56·17	56·16	56·96	57·40	57·34	57·16	...

JULY.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1804,	57·1	58·0	56·7	57·3	57·4	58·4	58·4	57·4	57·4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

JULY.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1804,	57·1	58·0	56·7	57·3	57·4	58·4	58·4	57·4	57·4	57·0	58·2	58·2	58·4	60·4	58·3	59·9
1821—1830,	56·4	56·9	56·9	58·0	58·6	56·4	56·8	57·4	57·7	56·5	58·6	57·1	59·4	59·2	59·4	59·5
1831—1840,	58·1	57·1	58·2	59·1	61·0	59·3	57·5	58·9	57·7	59·8	58·5	59·0	57·9	57·0	57·9	58·1
1841—1850,	56·7	56·6	57·4	58·3	56·1	56·8	56·7	57·3	55·9	59·3	58·0	60·6	60·3	59·4	58·9	58·3
MEAN,	57·12	57·17	57·30	58·20	58·31	57·75	57·36	57·79	57·19	58·19	58·35	58·74	59·02	59·04	58·62	58·99
Highest M. T. in 40 yrs.,	67·0	65·5	66·0	69·0	69·5	68·0	65·0	69·0	64·5	65·5	69·5	75·5	68·5	70·5	65·5	68·5
Lowest,	50·5	48·5	50·0	53·0	50·5	51·0	51·0	52·0	51·0	50·5	50·0	50·5	50·5	51·5	50·5	49·5
Fluctuation,	16·5	17·0	16·0	16·0	19·0	17·0	14·0	17·0	13·5	15·0	19·5	25·0	18·0	19·0	15·0	19·0

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1804,	59·3	59·5	58·2	59·1	59·7	60·1	58·7	58·8	57·8	58·8	59·2	58·9	58·0	58·3	59·7
1821—1830,	59·4	60·1	60·1	59·6	57·6	60·3	58·9	58·3	59·5	57·7	59·5	60·0	59·5	58·7	58·6
1831—1840,	57·9	56·8	56·7	56·8	56·3	55·1	56·7	57·7	58·4	59·1	59·7	61·1	58·6	58·6	59·0
1841—1850,	57·7	57·3	58·3	56·1	57·8	57·9	58·7	55·5	58·3	59·1	59·1	59·3	57·7	56·9	58·8
MEAN,	58·60	58·44	58·35	57·90	57·86	58·39	58·26	57·60	58·50	58·72	59·41	59·84	58·45	58·15	59·04
Highest M. T. in 40 yrs.,	72·0	77·0	67·5	65·5	65·5	66·5	67·5	70·0	67·5	68·0	68·0	68·0	68·0	68·5	70·5
Lowest,	48·0	49·0	51·5	51·5	53·0	51·5	51·0	51·5	51·5	51·5	53·0	54·0	50·5	51·0	51·5
Fluctuation,	24·0	28·0	16·0	14·0	12·5	15·0	16·5	18·5	16·0	16·5	15·0	14·0	17·5	17·5	19·0

AUGUST.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1805,	60·1	59·3	58·0	58·0	58·0	59·2	59·3	60·2	59·7	59·7	59·7	59·9	59·4	58·9	59·2	59·4
1821—1830,	56·8	58·9	58·5	57·9	57·5	56·3	58·2	58·9	58·2	56·5	57·6	56·0	55·0	55·9	56·2	53·5
1831—1840,	57·8	57·3	57·2	58·9	58·0	58·6	59·2	59·4	58·4	60·0	60·1	59·6	57·7	56·8	57·9	58·1
1841—1850,	58·9	57·8	56·7	57·2	56·8	58·6	57·5	58·1	57·5	56·5	56·9	58·0	58·9	57·0	56·7	56·5
MEAN,	58·42	58·35	57·64	58·02	57·62	58·20	58·56	59·20	58·46	58·19	58·57	58·39	57·76	57·16	57·52	56·90
Highest M. T. in 40 yrs.,	65·5	68·0	67·0	64·0	64·5	64·5	65·5	67·5	68·5	66·5	66·5	68·5	67·0	66·0	66·0	63·5
Lowest,	50·0	51·5	52·0	51·5	51·0	50·5	53·0	52·5	51·0	52·0	51·0	50·0	46·5	46·5	47·0	48·0
Fluctuation,	15·5	16·5	15·0	12·5	13·5	14·0	12·5	15·0	17·5	14·5	15·5	18·5	20·5	19·5	19·0	15·5

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1805,	60·4	59·7	60·0	57·6	57·8	57·7	58·2	57·5	57·0	56·8	56·9	57·7	58·7	57·7	55·2
1821—1830,	55·6	57·1	58·0	56·9	56·3	54·6	57·6	57·5	55·8	55·4	55·9	55·2	56·5	56·9	56·9
1831—1840,	57·0	58·3	57·8	58·1	57·4	55·6	56·8	55·1	55·0	55·3	55·9	54·6	53·8	54·5	54·1
1841—1850,	56·6	57·6	56·7	57·6	56·0	54·8	55·2	54·7	58·0	56·6	57·2	56·4	58·4	57·1	57·6
MEAN,	57·44	58.19	58·15	57·56	56·91	55·69	56·96	56·22	56·49	56·07	56·49	55·99	56·85	56·57	55·95
Highest M. T. in 40 yrs.,	67·0	70·5	70·5	68·0	67·5	65·0	64·5	63·0	64·5	63·0	64·5	63·0	66·5	64·5	66·5
Lowest,	49·0	49·0	48·0	48·0	48·5	49·0	48·0	50·0	51·0	50·0	46·5	46·0	47·5	49·0	47·5
Fluctuation,	18·0	21·5	22·5	20·0	19·0	16·0	16·5	13·0	13·5	13·0	18·0	17·0	19·0	15·5	19·0

SEPTEMBER.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1804,	56·2	56·4	56·2	55·4	55·6	56·1	55·4	55·3	55·3	55·9	54·4	52·5	55·1	56·4	57·2	56·8
1821—1830,	56·3	58·1	56·6	56·7	54·6	54·1	54·3	54·2	54·2	54·2	56·3	54·6	53·2	52·2	53·0	55·6
1831—1840,	54·4	53·4	52·9	53·9	54·5	54·8	54·9	53·0	54·3	52·5	51·6	52·0	51·8	51·7	52·8	53·1
1841—1850,	57·0	59·8	56·4	54·6	54·2	55·2	55·7	55·3	55·9	55·8	55·9	55·5	56·5	55·9	55·3	57·2
MEAN,	56·00	56·95	55·56	55·19	54·74	55·07	55·09	54·47	54·94	54·61	54·57	53·67	54·16	54·07	54·60	55·69
Highest M. T. in 40 yrs.,	65·0	72·0	67·5	65·0	64·5	65·5	66·5	63·0	62·5	64·0	66·0	66·0	64·5	66·0	65·0	64·0
Lowest,	48·0	48·0	47·0	47·0	47·0	47·5	45·0	47·5	47·0	46·5	45·5	40·5	42·5	44·0	45·5	45·0
Fluctuation,	17·0	24·0	20·5	18·0	17·5	18·0	21·5	15·5	15·5	17·5	20·5	25·5	22·0	22·0	19·5	19·0

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	
1795—1804,	55·8	55·5	54·3	52·8	51·4	51·4	50·3	50·1	51·2	52·3	51·0	52·4	52·3	51·3	...
1821—1830,	56·2	54·0	53·6	50·5	52·4	52·1	50·7	52·6	53·1	52·8	52·3	50·2	49·3	51·4	...
1831—1840,	52·9	51·8	52·3	52·8	52·4	51·7	52·6	53·3	52·2	52·8	53·2	51·4	51·6	50·7	...
1841—1850,	55·5	52·6	52·6	52·6	52·6	51·2	54·4	54·0	53·1	51·9	52·1	51·4	49·2	50·4	...
MEAN,	55·12	53·50	53·22	52·19	52·22	51·62	52·02	52·52	52·45	52·47	52·19	51·36	50·65	50·99	...
Highest M. T. in 40 yrs.,	63·0	62·5	63·0	61·0	62·5	60·5	63·5	62·0	64·5	62·0	61·0	61·5	61·0	62·0	...
Lowest,	43·5	43·5	47·0	44·5	42·0	39·5	42·5	43·5	43·0	42·0	40·0	39·0	35·5	44·5	...
Fluctuation,	19·5	19·0	16·0	16·5	20·5	21·0	21·0	18·5	21·5	20·0	21·0	22·5	25·5	17·5	...

OCTOBER.

	1.	2.	3.	4.	5.	6	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1804,	50·6	52·1	51·5	51·2	49·0	48·1	49·5	48·7	47·0	46·0	45·7	45·1	46·0	48·6	48·5	47·1
1821—1830,	51·1	49·3	52·8	52·3	50·9	51·6	50·9	49·2	47·8	49·2	48·6	48·2	47·3	46·3	45·7	48·5
1831—1840,	51·6	51·2	51·3	49·9	49·8	49·1	50·3	50·1	49·9	50·2	50·4	47·6	47·7	48·2	49·1	49·1
1841—1849,	51·5	50·9	48·6	48·1	49·5	49·6	49·6	48·5	49·8	49·4	49·9	47·1	46·1	47·9	46·3	45·0
MEAN,	51·22	50·91	51·07	50·41	49·82	49·61	50·12	49·15	48·62	48·74	48·67	47·04	46·82	47·77	47·41	47·47
Highest M. T. in 40 yrs.,	60·0	59·0	60·0	61·5	60·0	60·5	62·0	58·0	55·5	60·5	60·0	58·5	58·5	62·0	56·0	58·0
Lowest,	43·0	41·0	39·5	41·0	38·5	38·0	40·0	38·0	39·0	39·0	38·5	38·0	35·0	39·5	33·5	35·0
Fluctuation,	17·0	18·0	20·5	20·5	21·5	22·5	22·0	20·0	16·5	21·5	21·5	20·5	23·5	22·5	22·5	23·0

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
1795—1804,	46·3	46·6	46·8	47·7	47·4	45·4	44·0	45·1	45·8	44·0	43·2	43·4	44·0	45·6	44·7
1821—1830,	46·8	44·6	47·8	49·3	48·0	47·8	47·7	49·4	49·1	46·1	47·4	45·2	43·8	44·3	44·6
1831—1840,	50·4	48·8	47·7	48·7	48·6	49·4	47·2	45·9	44·4	45·0	45·9	43·0	43·0	44·4	43·8
1841—1849,	46·5	45·9	46·1	45·1	41·8	44·4	46·3	43·7	42·8	41·6	43·6	44·6	44·5	45·1	45·9
MEAN,	47·51	46·50	47·12	47·72	46·50	46·76	46·32	46·04	45·54	44·20	45·05	44·09	43·85	44·86	44·76
Highest M. T. in 40 yrs.,	57·0	59·5	60·5	56·5	56·5	56·0	61·0	58·5	56·0	54·0	53·5	54·5	52·5	55·5	54·0
Lowest,	35·5	34·0	35·0	34·5	35·0	37·0	38·0	34·0	38·5	35·5	32·0	31·5	30·0	30·5	29·5
Fluctuation,	21·5	25·5	25·5	22·0	21·5	19·0	23·0	24·5	17·5	18·5	21·5	23·0	22·5	25·0	24·5

NOVEMBER.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1864,	44·4	44·3	41·0	40·0	40·6	41·8	43·1	40·6	39·9	39·4	40·3	40·7	40·8	41·5	40·3	40·1
1821—1830,	44·8	45·8	45·8	42·3	43·0	42·3	41·9	40·2	41·1	41·8	42·8	42·3	44·6	43·7	41·6	40·3
1831—1840,	44·8	44·6	43·1	41·2	42·3	39·4	40·4	41·5	41·4	42·9	42·5	41·8	40·8	39·3	39·5	40·5
1841—1849,	46·5	44·6	43·6	43·4	42·5	45·8	44·8	46·1	45·1	45·0	43·1	41·5	41·5	40·6	40·9	42·6
MEAN,	45·14	44·86	43·41	41·74	42·14	42·35	42·59	42·12	41·90	42·30	42·19	41·57	41·96	41·29	40·59	40·90
Highest M. T. in 40 yrs.,	53·5	53·0	51·0	52·5	55·0	52·5	51·5	54·5	51·0	54·0	54·5	54·5	53·0	52·0	56·0	50·0
Lowest,	32·5	36·5	29·5	32·0	32·5	34·0	32·0	33·5	30·0	27·0	32·0	30·5	34·5	32·0	31·0	31·5
Fluctuation,	21·0	16·5	21·5	20·5	22·5	18·5	19·5	21·0	21·0	27·0	22·5	24·0	18·5	20·0	25·0	18·5

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	
1795—1864,	40·7	38·9	37·5	37·4	37·1	37·8	36·8	36·6	35·2	36·4	36·5	35·2	36·9	36·3	...
1821—1830,	41·9	38·8	39·9	42·7	44·0	40·4	41·1	41·1	39·8	41·7	39·7	41·3	40·9	38·6	...
1831—1840,	40·1	39·6	40·9	39·8	40·5	42·3	42·6	41·7	39·0	38·4	37·9	38·8	40·8	43·4	...
1841—1849,	43·8	42·1	43·1	43·3	42·4	40·8	38·9	39·2	39·4	41·3	42·4	40·5	41·6	39·6	...
MEAN,	41·66	39·85	40·36	40·84	41·01	40·35	39·89	39·67	38·40	39·46	39·12	39·00	40·10	39·52	...
Highest M. T. in 40 yrs.,	53·0	51·0	50·0	51·0	54·5	51·0	53·0	52·5	52·0	51·5	53·0	51·0	52·0	50·5	...
Lowest,	29·5	30·0	27·5	26·0	31·0	30·0	25·5	28·5	29·5	28·5	27·5	26·0	24·0	25·5	...
Fluctuation,	23·5	21·0	22·5	25·0	23·5	21·0	28·5	24·0	22·5	23·0	25·5	25·0	28·0	25·0	...

DECEMBER.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1795—1804,	37·5	36·9	35·0	33·4	35·9	36·3	37·2	35·5	37·0	37·4	36·7	36·3	36·6	35·8	37·3	38·2
1821—1830,	37·0	37·6	37·7	38·8	37·6	38·8	41·0	40·9	41·0	40·7	42·2	41·9	41·6	40·3	42·5	41·6
1831—1840,	42·4	41·3	42·1	43·7	41·0	40·8	41·1	40·4	41·8	39·6	39·7	39·8	40·6	39·6	38·7	40·9
1841—1849,	41·6	42·0	42·1	40·3	39·3	38·7	39·4	40·0	41·1	42·7	41·5	40·7	40·0	41·4	42·1	41·5
MEAN,	39·66	39·45	39·25	39·10	38·47	38·67	39·71	39·22	40·24	40·12	40·05	39·70	39·72	39·30	40·16	40·55
Highest M. T. in 40 yrs.,	49·0	52·0	52·0	51·0	51·0	54·0	48·0	49·5	51·5	55·0	52·5	50·5	53·5	53·5	53·5	51·5
Lowest,	26·5	31·0	28·5	26·0	22·5	23·0	28·5	24·0	28·5	28·5	27·5	29·0	26·0	26·5	28·5	28·0
Fluctuation,	22·5	21·0	23·5	25·0	28·5	31·0	19·5	29·5	23·0	26·5	25·0	21·5	27·5	27·0	25·0	23·5

	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29	30.	31.
1795—1804,	37·2	37·3	37·7	36·1	36·4	37·3	36·0	34·9	34·4	35·4	35·3	35·1	34·9	35·6	33·6
1821—1830,	41·5	40·7	39·1	38·1	38·4	38·0	35·8	38·0	38·9	35·5	35·5	35·1	35·2	36·9	36·3
1831—1840,	40·9	39·1	40·0	39·2	40·2	40·0	38·7	38·9	39·1	37·3	36·4	36·1	37·9	39·4	38·8
1841—1849,	38·8	38·8	39·1	39·0	37·3	38·4	35·3	36·1	38·4	39·6	37·1	35·8	38·8	39·9	38·4
MEAN,	39·62	39·00	38·99	38·12	38·09	38·46	36·46	37·00	37·72	36·96	36·12	35·54	36·72	37·95	36·77
Highest M. T. in 40 yrs.,	45·0	50·0	50·0	48·5	50·5	52·5	46·5	50·0	51·0	52·5	48·0	47·5	49·5	50·0	53·0
Lowest,	28·5	27·5	25·0	29·0	23·5	23·0	19·0	18·5	13·0	22·5	23·5	21·5	25·0	24·5	20·0
Fluctuation,	16·5	22·5	25·0	19·5	27·5	29·5	27·5	31·5	32·0	30·0	24·5	26·0	24·5	25·5	33·0

59. The preceding table (pp. 348–49) contains the synopsis of the whole thermometric observations described in Section 2, arranged under each day of the year, and divided into four decennial periods. From these partial results, the great length of period required to determine the mean temperature of any given day may be estimated. I have farther added the extremes of the observed mean temperature of the day during forty years, and the difference of these, which I call the "fluctuation." This uncertainty as to the mean temperature of a given day amounts occasionally in winter and spring to 30° Fahr. or more.

60. The mean daily temperatures in the preceding Table are projected on a large scale in Plate XVIII. Notwithstanding the casual sinuosities of the curve of temperature from day to day, the interpolating curve derived from the formula obtained in Art. 56 evidently represents the course of temperature with general exactness, and the temperature of a given day may be estimated from it with far more accuracy than by the observed mean of that day only, even if derived from forty years' observations.

61. Nevertheless, it is interesting and important to ascertain whether there are not *partial inflections* of the annual curve, subject to recur, and which cannot be satisfactorily represented by the usual periodic series. These are fitly termed by M. QUETELET "periodic anomalies." *

62. With this object in view, as well as to facilitate a comparison of the Edinburgh temperatures with observations made elsewhere, I caused the *five-day means* to be taken from one end of the year to the other (derived from the collective observations of 40 years), in the same way that was done by the earlier meteorologists, and more lately by M. DOVE, who has published a considerable collection of such results.† By this process the sinuosities of the larger curve are very much reduced, and anything like a systematic deviation from symmetry is more clearly shown.

63. The results are contained in the following table, and are represented in Plate XIX.

* Memoire, &c., p. 4.

† DOVE, Fünftägige Mittel, &c. Folio, Berlin: and in the Tables of the Prussian Statistical Bureau. Folio, 1858.

TABLE XIII.—SHOWING THE FIVE-DAY MEANS OF TEMPERATURE FOR FORTY YEARS, AS OBSERVED AND AS COMPUTED FROM THE FORMULA; ALSO THE FLUCTUATION OF DAILY TEMPERATURE IN FORTY YEARS, AND THE MEAN DAILY RANGE (TWENTY-NINE YEARS' AVERAGE).

	Temperature.		Diff.	Daily Fluctuation in 40 Years.	Mean Daily Range.		Temperature.		Diff.	Daily Fluctuation in 40 Years.	Mean Daily Range.
	Calculated.	Observed.					Calculated.	Observed.			
Jan. 1–5	36°·92	36°·30	−0°·62	24°·4	9°·4	July 5–9	58°·00	57°·68	−0°·32	16°·1	16°·9
6–10	36·76	35·84	− ·92	24·4	9·5	10–14	58·30	58·67	+ ·37	19·3	16·5
11–15	36·74	35·97	− ·77	27·5	9·4	15–19	58·54	58·60	+ ·06	20·4	16·1
16–20	36·72	37·06	+ ·34	29·6	9·6	20–24	58·71	58·00	− ·71	15·3	15·8
21–25	36·78	37·65	+ ·87	28·2	10·3	25–29	58·78	58·98	+ ·20	15·8	17·0
26–30	36·82	37·34	+ ·52	26·6	10·5	30–3	58·69	58·32	− ·37	16·7	16·5
31–4	37·06	37·16	+ ·10	28·0	10·6	Aug. 4–8	58·52	58·32	− ·20	13·5	16·5
Feb. 5–9	37·27	37·55	+ ·28	26·8	10·6	9–13	58·24	58·27	+ ·03	17·3	16·5
10–14	37·54	38·33	+ ·79	26·1	11·1	14–18	57·81	57·44	− ·37	18·7	15·7
15–19	37·80	37·94	+ ·14	25·3	11·2	19–23	57·37	57·05	− ·32	18·8	15·7
20–24	38·21	38·35	+ ·14	23·2	10·8	24–28	56·80	56·25	− ·55	14·9	16·0
25–1	38·60	38·32	− ·28	26·0	11·3	29–2	56·12	56·46	+ ·34	18·9	16·1
Mar. 2–6	39·08	38·96	− ·12	21·5	12·5	Sept. 3–7	55·36	55·13	− ·23	19·1	15·4
7–11	39·53	39·91	+ ·38	24·7	13·9	8–12	54·54	54·45	− ·09	18·9	16·0
12–16	40·11	40·74	+ ·63	25·3	13·3	13–17	53·62	54·73	+1·11	20·4	15·7
17–21	40·66	41·38	+ ·72	21·4	14·0	18–22	52·71	52·55	−0·16	18·6	15·1
22–26	41·35	41·01	− ·34	21·0	13·7	23–27	51·72	52·33	+ ·61	20·4	14·2
27–31	42·03	41·94	− ·09	22·2	14·3	28–2	50·70	51·03	+ ·33	20·1	14·9
April 1–5	42·75	42·82	+ ·07	22·3	14·6	Oct. 3–7	49·57	50·21	+ ·64	21·4	13·5
6–10	43·44	43·73	+ ·29	20·7	14·9	8–12	48·61	48·44	− ·17	20·0	12·6
11–15	44·30	44·37	+ ·07	20·7	15·7	13–17	47·55	47·40	− ·15	22·6	13·1
16–20	45·08	45·28	+ ·20	21·0	16·1	18–22	46·53	46·92	+ ·39	22·7	13·1
21–25	46·01	45·49	− ·52	22·9	15·5	23–27	45·44	45·43	− ·01	21·0	12·0
26–30	46·92	47·37	+ ·45	19·8	16·3	28–1	44·54	44·54	·00	23·2	12·2
May 1–5	47·79	48·21	+ ·42	19·0	17·1	Nov. 2–6	43·55	42·90	− ·65	19·9	11·1
6–10	48·70	48·14	− ·56	20·5	16·5	7–11	42·69	42·22	− ·47	22·2	10·6
11–15	49·64	48·60	−1·04	20·3	17·6	12–16	41·79	41·26	− ·53	21·2	10·9
16–20	50·55	50·69	+0·14	21·5	17·5	17–21	41·05	40·74	− ·31	23·1	11·2
21–25	51·49	52·34	+ ·85	20·2	16·7	22–26	40·35	39·55	− ·80	23·8	10·6
26–30	52·38	52·99	+ ·61	23·3	17·5	27–1	39·64	39·48	− ·16	25·2	10·0
31–4	53·27	54·03	+ ·76	20·1	18·0	Dec. 2–6	39·01	38·99	− ·02	25·8	9·8
June 5–9	54·08	54·41	+ ·33	22·9	17·5	7–11	38·53	39·87	+1·34	24·7	9·7
10–14	54·93	55·68	+ ·75	21·5	17·9	12–16	38·00	39·89	+1·89	24·9	9·9
15–19	55·64	56·00	+ ·36	19·5	17·9	17–21	37·69	38·76	+1·07	22·2	9·7
20–24	56·36	56·39	+ ·03	18·8	17·7	22–26	37·32	37·32	0·00	30·1	9·7
25–29	56.96	56·81	− ·15	21·7	17·7	27–31	37·11	36·62	− ·49	26·7	9·7
30–4	57·50	57·39	− ·11	17·0	17·6						

64. In this Table I have included the five-day means of the "fluctuation" of temperature for forty years for a given day, deduced as above; also the "mean

daily range," deduced from the average of all the daily extremes for twenty-nine years (1822–1850), during which self-registering thermometers were in use.* I shall make a few observations under each of these heads.

(1.) *On the inflections, or "periodic anomalies" of the annual curve, compared with the standard or computed values.*

65. Of these the most marked, indicated by the Curve and the Table last referred to, is an excess of temperature above the calculated or normal amount in the latter part of January and earlier part of February. This is a well-known and long recognised anomaly. In most European instances it affects materially the mean temperature of February, which is very commonly far too high, when contrasted with the general sweep of the annual curve. At Brussels, for example, M. Quetelet finds an excess in the temperature of February above the general curve of at least 1°·5 Fahr. The same peculiarity may be noticed in the annual curves of London, Prague, St Petersburg, Vienna, and many other places, including even the Great St Bernard. If it is nearly insensible in the monthly means of Table XI. p. 346, this apparently arises from the anomaly occurring rather sooner at Edinburgh than in most other places, and therefore affecting the temperature of January fully as much as that of February.

66. In connection with this anomaly, I may observe that it is apparently connected with an anomalous depression of the thermometer in the early part of January, of which it may be said to be the reaction. Although we have seen (Art. 57), that in the equalized curve of temperature the minimum is attained on the 17th January (and if two terms of the equation alone were used, it would be on the 22d), the average coldest day is very decidedly earlier in the month. This is well shown in both the detailed curve and the curve of five-day means. The 11th January is the average coldest day (Table IX.), and it is also the central point of an abnormal depression of temperature. The same thing is well marked in M. Quetelet's curves, which coincide almost to a day with the preceding results.†

67. Of the other periodic inequalities of the annual curve we cannot speak with much confidence. Even after forty years' observations, the casual fluctuations of daily temperature are far from being eliminated; and for a period of ten, or even twenty years, very great uncertainty still remains, as may easily be concluded from a comparison of the numbers under each day in Table XII. for the four decennial periods. Perhaps the general depression of temperature in the month of November, which is also traceable in the curves of Greenwich and Brussels, may be considered as a true periodic anomaly, at least in this part of the world.

* The reductions of the daily range have been less scrupulously verified than most of the other computations contained in this paper, but any residual errors are hardly likely to affect sensibly the mean results.

† Since writing the above, I notice that M. Quetelet, at page 39 of his Memoir, expresses himself as to this anomaly in almost the same terms that I have used.

A sort of reaction appears in a comparatively limited yet marked excess of temperature, during the middle fortnight of December. This excess is clearly indicated in every one of the four decennial periods. About the 12th May there is also a brief depression of temperature, which, so far, appears to confirm the existence of the three cold days (11th, 12th, and 13th May) mentioned by Humboldt,* which likewise seem to be indicated at Greenwich; but these deductions are of a description not much to be relied on, and, after all, they most likely depend on causes more or less local.

(2 *and* 3). *On the "fluctuation" of daily mean temperature, and on the diurnal range.*

68. If we project, in the form of a curve, the fluctuation of the daily mean temperature for forty years included in Mr ADIE'S observations (as shown in column 5 of Table XIII.), we find a very remarkable variation with the season of the year. There appears to be the least casual fluctuation about the end of July, when it amounts to about 16° or 17°, and the maximum occurs nearly six months later, or about the middle of January, when it may be reckoned at between 28° and 29°. These periods coincide, it will be observed, nearly with the hottest and coldest seasons. It may be accidental, but I cannot help remarking, that for some days together these values of "fluctuation" range remarkably low, and then for another short period as uniformly high. An example of this may be noticed in Table XII. for the latter part of December.

69. The other element, the diurnal range, or mean daily difference of maximum and minimum readings for twenty-nine years, gives us a curve of a nearly opposite form to the preceding, and much more regular. The minimum range of 9°·5 occurs in the end of December or beginning of January; the maximum of nearly 18° between the middle and end of June.

SECT. 7. *Remarks on the Price of Corn during Fifty-six years, as compared with Meteorological Data.*

70. It will be recollected that Sir William Herschel, when investigating the connection of the solar spots with terrestrial temperature, employed (though not without some reserve, and only in the absence of better data) the price of wheat as an indication of the heat or cold of different years.

71. I thought it might be worth while to test roughly the applicability of such a scale of climate; and I even considered that it might be practicable to express the relation of the abundance of corn to the meteorological elements which might be expected chiefly to influence it. These expectations signally failed. But I think it may be instructive to record the failure, at a time when agriculturists are directing their attention to meteorology.

* Cosmos, vol. i. note 86.

72. I decided to use the price of oats in the Edinburgh market as the fairest test of the state of the harvest, being at once the most abundant crop, and the one least likely to be affected by foreign importations and by fiscal enactments. In this view I was confirmed by two eminent agricultural authorities.

73. To Mr Charles Lawson I am indebted for a table of the average price of oats of first and second quality, in the Edinburgh market for each year from 1795 to 1850 inclusive (with the exception of the year 1805). The following Table contains the prices of the first quality, in chronological order, and the differences + or − (neglecting fractions of a penny) from the mean of the whole, which is 18s. 11d. per boll of six bushels:—

TABLE XIV.—Showing the Price of Oats (First Quality) in the Edinburgh Market, per Boll of Six Bushels, from 1795 to 1850 inclusive.

		Difference from Mean.			Difference from Mean.			Difference from Mean.
	s. d.	s. d.		s. d.	s. d.		s. d.	s. d.
1795	19 6	+ 0· 7	1814	18 3	− 0· 8	1833	13 6	− 5· 5
1796	14 4	− 4· 7	1815	14 3	− 3· 8	1834	15 0	− 3·11
1797	13 6	− 5· 5	1816	25 11	+ 7· 0	1835	15 0	− 3·11
1798	14 0	− 4·11	1817	23 0	+ 4· 1	1836	20 9	+ 1·10
1799	29 4	+10· 5	1818	23 0	+ 4· 1	1837	15 7½	− 3· 4
1800	33 2	+14· 3	1819	17 6	− 1· 5	1838	21 0	+ 2· 1
1801	16 6	− 2· 5	1820	16 0	− 2·11	1839	18 6	− 0· 5
1802	15 6	− 3· 5	1821	15 4	− 3· 7	1840	14 7½	− 4· 4
1803	17 6	− 1· 5	1822	15 0	− 3·11	1841	14 7½	− 4· 4
1804	18 6	− 0· 5	1823	20 0	+ 1· 1	1842	14 3	− 4· 8
1805	...	...	1824	17 10	− 1· 1	1843	15 9	− 3· 2
1806	20 0	+ 1· 1	1825	18 4	− 0· 7	1844	16 3	− 2· 8
1807	27 0	+ 8· 1	1826	25 9	+ 6·10	1845	20 0	+ 1· 1
1808	24 0	+ 5· 1	1827	17 0	− 1·11	1846	26 3	+ 7· 4
1809	29 9	+10·10	1828	18 6	− 0· 5	1847	18 1½	− 0·10
1810	18 0	− 0·11	1829	16 3	− 2· 8	1848	14 3	− 4· 8
1811	23 0	+ 4· 1	1830	20 0	+ 1· 1	1849	12 3	− 6· 8
1812	31 6	+12· 7	1831	17 6	− 1· 5	1850	13 6	− 5· 5
1813	21 6	+ 2· 7	1832	14 1½	− 4·10			
						Average,	18 11	

74. The next Table shows the seasons arranged according to the dearness of oats, or the reverse.

TABLE XV.—CONTAINING THE SEASONS ARRANGED ACCORDING TO THE PRICE OF OATS, BEGINNING WITH THE CHEAPEST.

1.	1849	9.	1848	17.	1802	25.	1803	33.	1804	41.	1836	49.	1816
2.	1797	10.	1796	18.	1837	26.	1819	34.	1828	42.	1838	50.	1846
3.	1833	11.	1840	19.	1843	27.	1831	35.	1839	43.	1813	51.	1807
4.	1850	12.	1841	20.	1820	28.	1824	36.	1795	44.	1811	52.	1799
5.	1798	13.	1822	21.	1829	29.	1810	37.	1806	45.	1817	53.	1809
6.	1832	14.	1834	22.	1844	30.	1847	38.	1823	46.	1818	54.	1812
7.	1815	15.	1835	23.	1801	31.	1814	39.	1830	47.	1808	55.	1800
8.	1842	16.	1821	24.	1827	32.	1825	40.	1845	48.	1826	...	...

75. If this Table be compared with similar ones of the different meteorological data in the earlier part of this paper, the complete discordance from all or any of these will be perceived. It is true that the cold years of 1799, 1800, and 1812, certainly coincide with periods of dear corn; but, on the other hand, we find them in close proximity with 1826 and 1846, the two hottest summers of the record. On the other hand, the cheapest years of the whole, 1849 and 1797, will be seen from Table X. to have been cold, late, and rainy. I have in that Table included the character of the season as one of cheapness or of scarcity, in anticipation of this comparison.

76. It might be suggested that the abundance, or the contrary, of the crop of any year might be expected rather to influence the prices of the next than of that season; but this supposition does not seem to reconcile the anomaly. Thus, the cold years 1797 and 1849 were not only cheap years, but were succeeded by cheap years; and the hot summers of 1826 and 1846 produced not only high prices, but were succeeded by years of only average prices.

77. With a view to test impartially the possible connection between prices and these elements of climate, I assumed that it might be possible to represent the price of oats in any year by a linear function of the following variables—viz., the mean temperature of the year, the temperature of the hottest month, and the fall of rain. I accordingly wrote out (without selection) those data for the following years of those for which I possessed complete records—viz., the three dearest, the three cheapest, the three years having the highest mean temperature, the three having the lowest mean, the three having the hottest summer months, and the three wettest years. I took the mean of the three years of the same description, and thus obtained six equations of a linear form, each containing three factors as multipliers of the meteorological elements, which factors were to be determined. It will show the extreme anomaly of the results that the mean of the three years of most rain showed a price of oats rather *below* the average, that the three hottest years were *above* the average. The six equations being solved separately

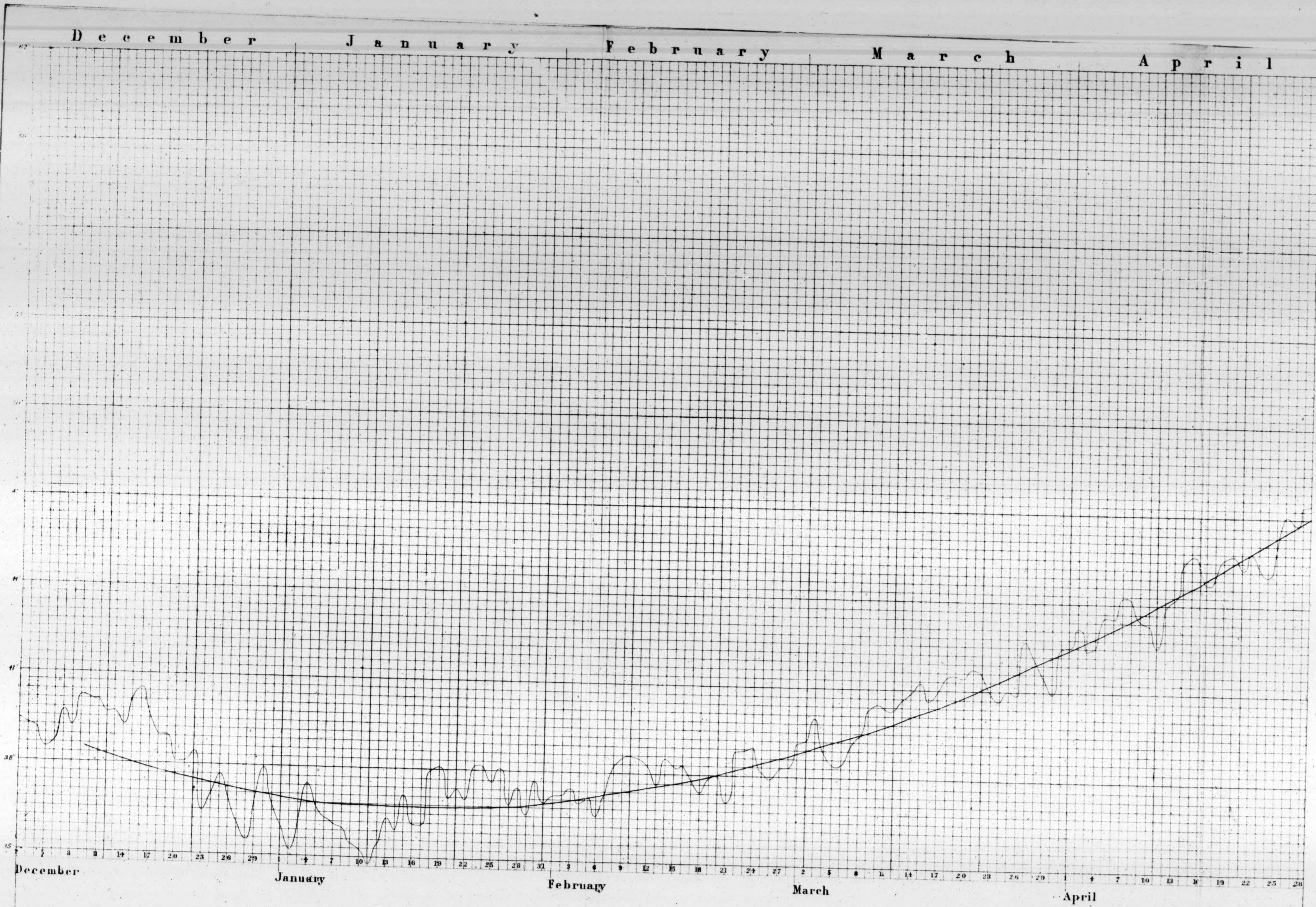
in two groups of three, each give constant factors of the meteorological elements so extravagantly wide of one another as not to be worth reporting.

78. It may of course be said that the meteorological data affecting the harvest are mainly confined to one critical period of the year. It is also true that *extremes*, whether of heat or cold, drought or wet, are not favourable to abundant harvests.* Making all allowances, however, the results are exceedingly anomalous, and seem to show that the price of corn cannot be used to afford the slightest clue to the temperature or meteorological character of a given season.

Postscript.

I have already acknowledged the assistance which I have derived from Mr Grassick, and especially from Mr Balfour Stewart, in the preparation of this paper. I have farther to add, that I am indebted to Mr Stewart for the projection of the curves of Plates XVIII. and XIX., and to Mr Robert Cram for the calculation of several of the Tables.

* The same remark is made in page 39 of Mr Jenyns' "Observations on Meteorology," a very carefully compiled work. It might be possible to include this view of the case by considering the prices to vary with the *square* of the departures of the meteorological elements from a certain amount most favourable to cultivation, but I find no encouragement to make a fresh calculation on this more complex system.



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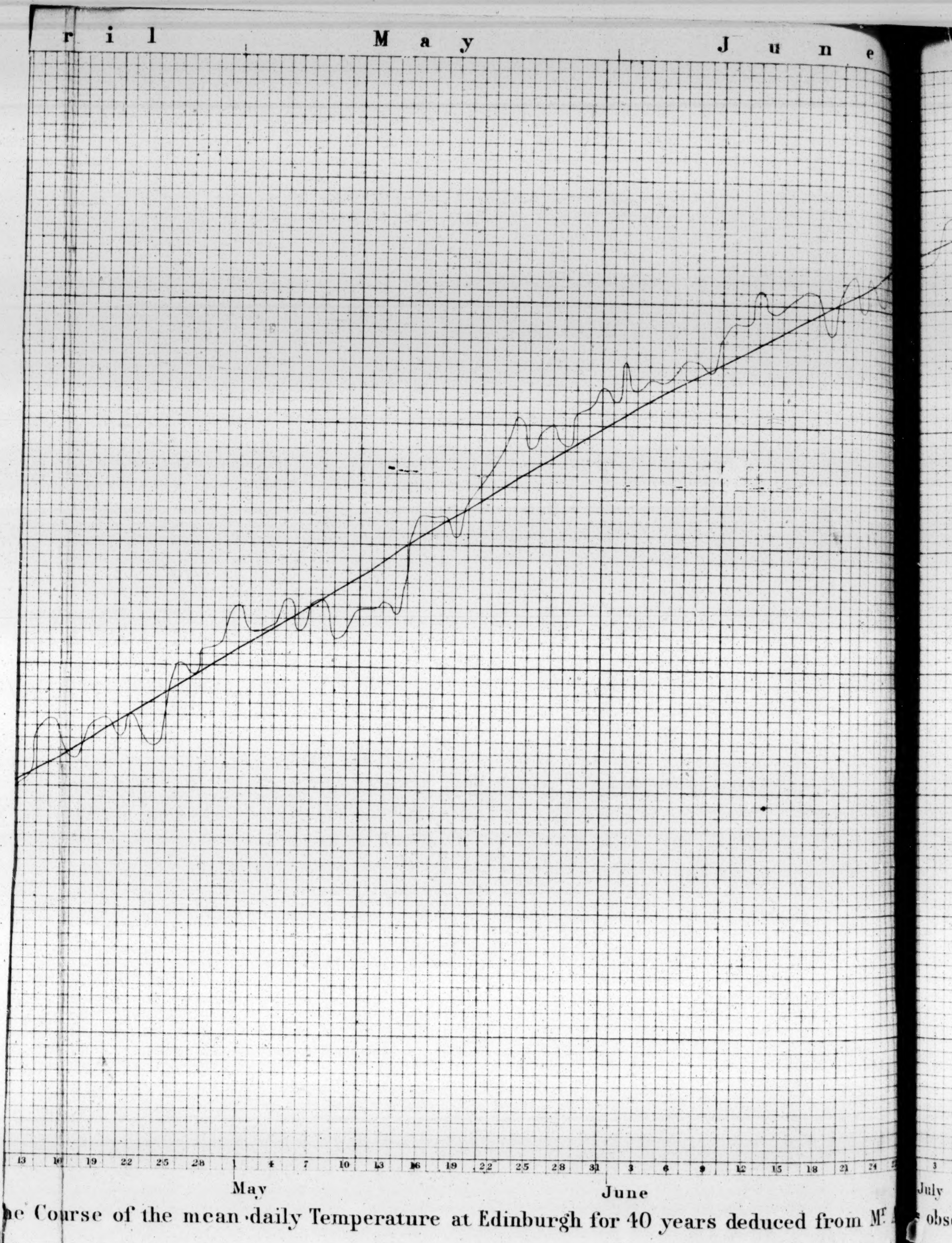
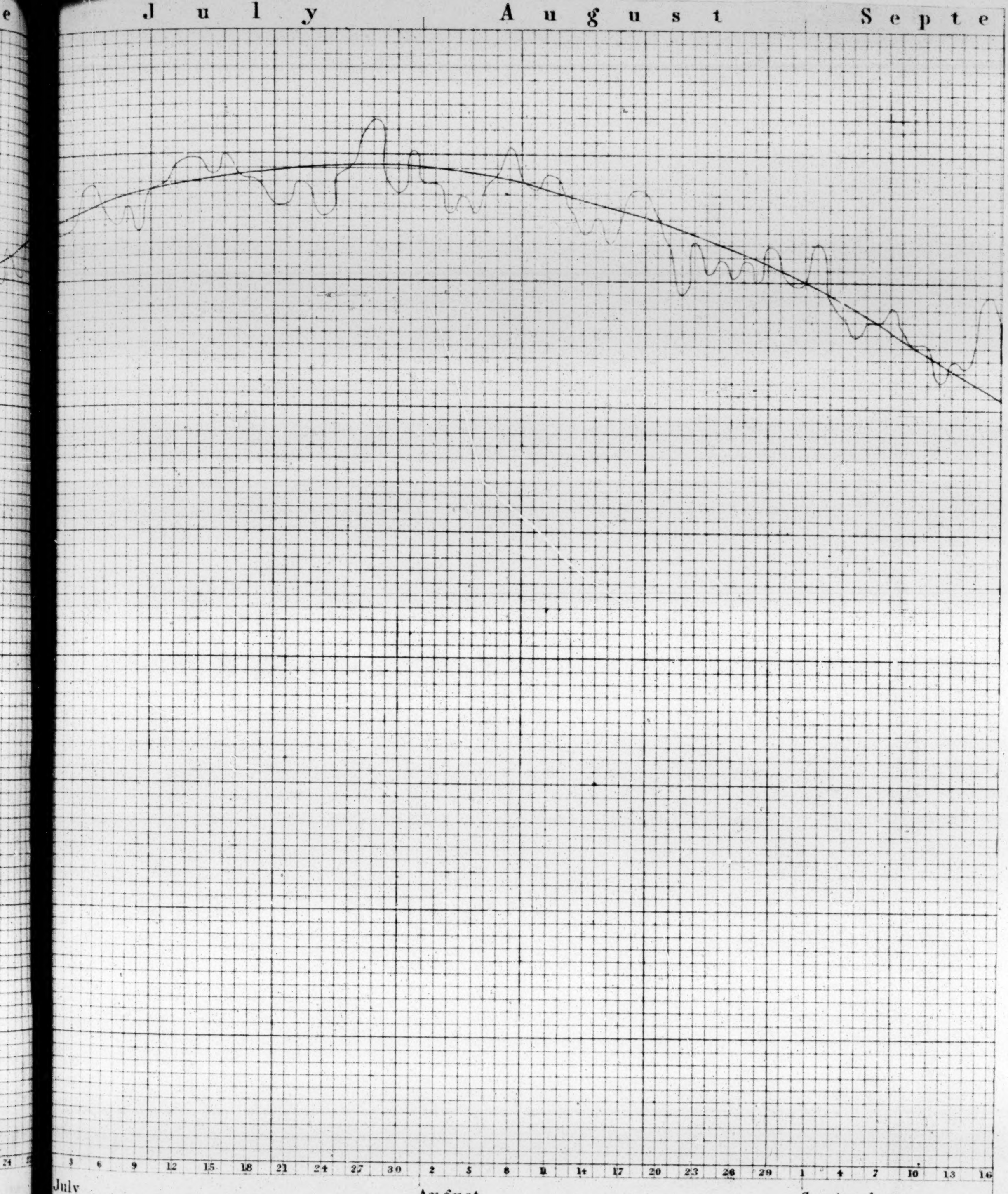
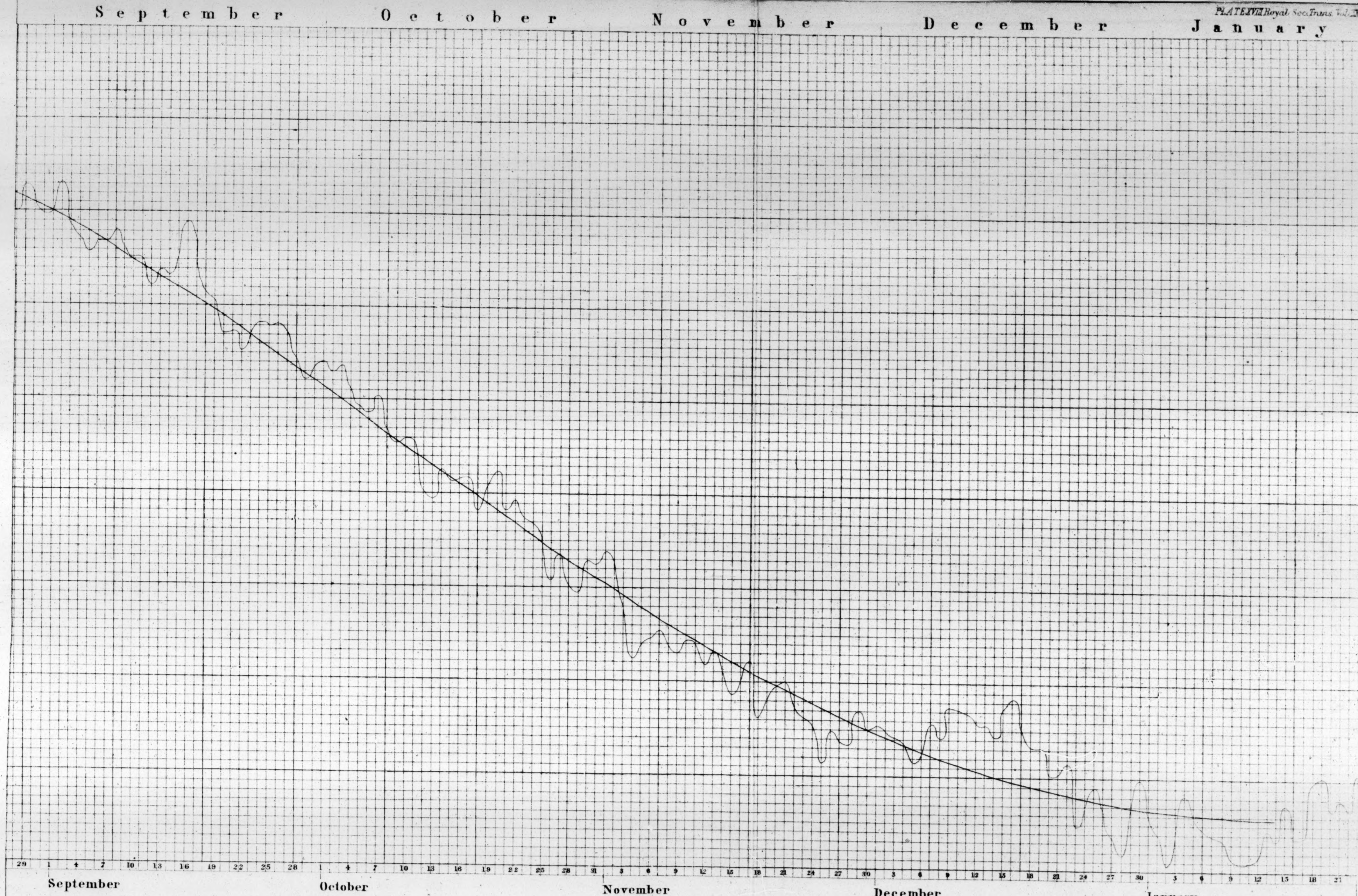


he Course of the mean daily Temperature at Edinburgh for 40 years deduced from Mr. ... obs



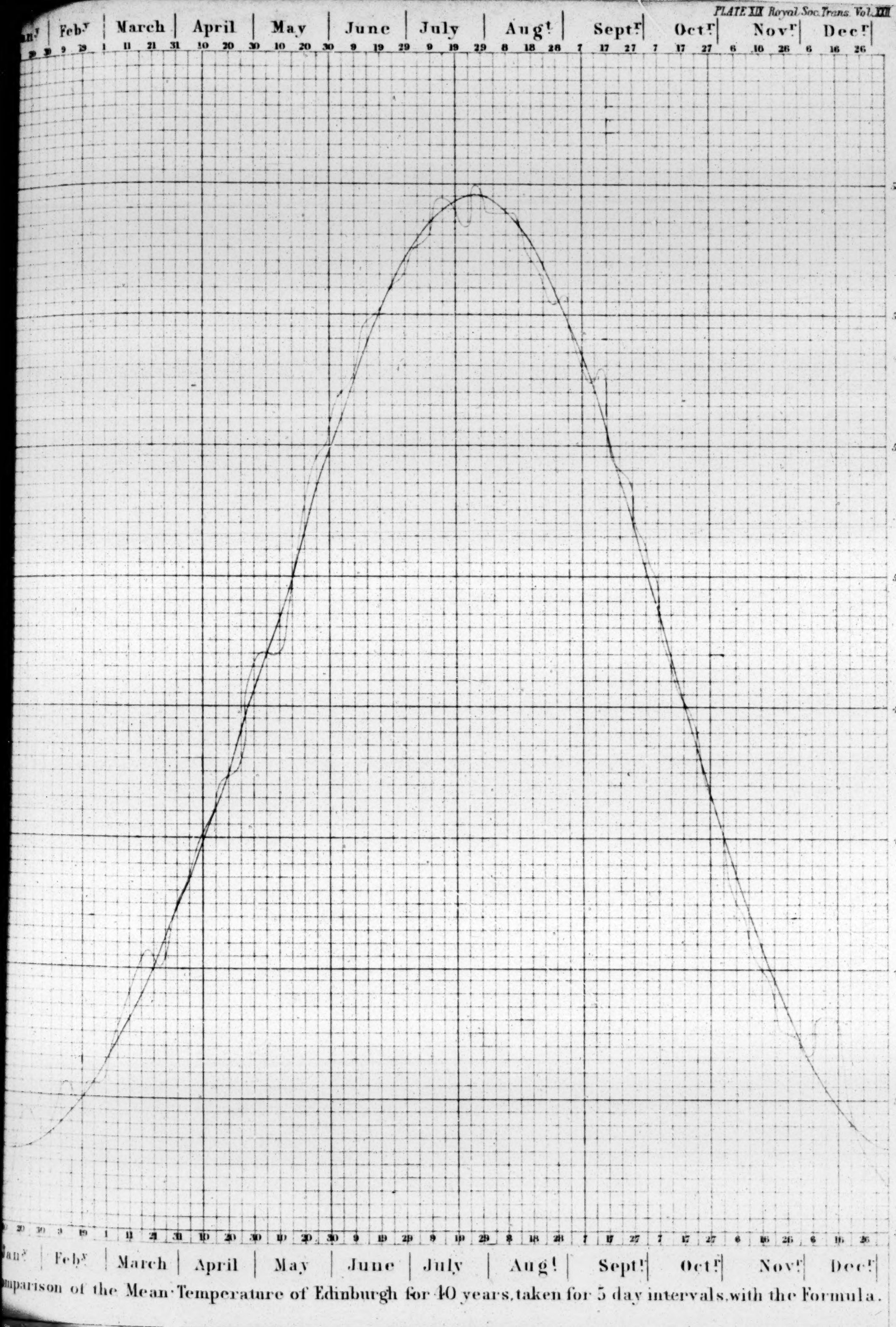
Mr. [illegible] observations & compared with the Formula $y = 46^\circ 88' - 10^\circ 98$ Sine $(x + 68^\circ 28') + 0^\circ 9$[illegible]

PLATE XVIII Royal Soc. Trans. Vol. XXII



Sine $(x + 68° 28') + 0° 96$ Sine $(2x + 22°)$

W. & A. K. Johnston, Edinburgh.



[Co]mparison of the Mean Temperature of Edinburgh for 40 years, taken for 5 day intervals, with the Formula.

W. & A. K. Johnston Edinburgh

XIII.—*Account of a Thermometrical Register kept at Dunfermline by the Rev. Henry Fergus, from 1799 till 1837, with the principal Results.* By JAMES D. FORBES, D.C.L., F.R.S., Sec. R.S. Ed., Professor of Natural Philosophy in the University of Edinburgh.

(Read 6th March 1860.)

1. When I found that the interesting meteorological register of Mr ADIE, which is well fitted to throw light upon the climate of Edinburgh, and of Scotland generally, was deficient of the important period of nearly sixteen years, from 1805 to 1820, I set on foot inquiries as to the existence of any other register of the thermometer which might approximately supply the defect. After some unsuccessful attempts, my attention was directed by Professor DOVE's useful temperature tables to a register of the thermometer kept by the Rev. Mr FERGUS of Dunfermline, of which the monthly means, from 1805 to 1824, are given in the "Edinburgh Philosophical Journal," vol. xiii. Though the distance of Dunfermline from Edinburgh is thirteen miles in a right line, and though it occupies the opposite slope of the valley of the Forth, not far from the Ochil Hills, yet a slight comparison of the observations showed a very remarkable coincidence in its climate with that of Edinburgh, not only as regards the mean annual temperature, but also in the distribution of temperature throughout the year. I therefore made an effort to obtain the original register from which the results published in the "Edinburgh Philosophical Journal" were derived; and through the kindness, in the first instance, of Mr DAVID LAING of the Signet Library, I was brought into communication with the Rev. JOHN FERGUS of Bower, near Wick, in Caithness, son of the Dunfermline observer, who most kindly placed in my hands his father's original register of the barometer, thermometer, and weather at Dunfermline, extending from 1799 to the time of his death in 1837, all made with one instrument, and at the same hour daily (9 A.M.), with very remarkable regularity.

2. During this long period of time but one thermometer was used, and it is still entire, and now in my possession.

3. From November 1802 until August 1837 the thermometer appears to have been constantly kept in the same exposure, which was rather a peculiar one, and which has been minutely described to me by the Rev. JOHN FERGUS. It was placed on the outside of an ordinary glazed window, in a staircase leading to an attic, with a north exposure. This window was above $3\frac{1}{2}$ feet wide, but, in order to avoid the window-tax, it was contracted externally by brickwork, so as to leave

in the centre of the lower part an unglazed opening 9 inches square, which admitted air freely to the interval between the brick wall and the window. The thermometer was suspended in this interval, into which the snow often drifted.

4. The effect of this peculiarity of exposure would probably be to modify the extremes both of heat and cold, but (especially for observations taken at 9 A.M.) it was not likely to affect materially the *mean* results.

5. The observations from May 1799 to November 1802, when the thermometer was moved into this position, seem (to judge by their results) to have been made probably *within* the house, and therefore I have not retained them in the following paper. Till August 1829 the observations were invariably made by Mr FERGUS, senior, when the failure of his eyesight devolved them (I believe) upon some member of his family; but they were still continued in all respects in the same manner until the commencement of September 1837, when the instrument was removed to a different situation in the town of Dunfermline, where it was rather exposed to reflected heat; and in 1842 it was transferred to a different part of the country. Two years later it was removed to Edinburgh, where I found it in April 1857, in the custody of Mrs FERGUS, widow of the original observer who had begun to use it nearly 60 years before. That lady confirmed the history of the observations, and the fact of its being one and the same instrument which was used from the first. She kindly placed it at my disposal for the purpose of comparison.* I found it to be a spirit of wine thermometer by KNIE, a very well known Edinburgh maker of the last century. The colour of the spirit was unimpaired (a circumstance very rare in modern thermometers), and the scale was of ivory clearly divided. Unfortunately the tube was fixed to the scale with thread in an insecure manner, so as to leave some uncertainty as to the precise reading. On a comparison with a standard thermometer, *corrections to the scale readings* of KNIE's thermometer were obtained within the limits of the monthly temperatures, and, by the aid of an interpolating curve, the following *approximate* corrections ascertained, which were then applied to the monthly averages calculated anew from Mr FERGUS' MS. volume:—

Corrections to Scale Readings of the Dunfermline Thermometer.

At temp. 32°	−0°·5	At temp. 50°	+0°·6
40	−0·3	55	+0·9
45	+0·1	60	+0·9

* This lady died at an advanced age in the interval between the writing of this paper and its being read.

6. The monthly average temperatures to 1830 are contained in the following Table:—

TABLE XVI.—DUNFERMLINE OBSERVATIONS CORRECTED FOR INDEX ERROR.

A.D.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1803	35°·4	35°·8	39°·6	45°·3	48°·9	54°·3	63°·5	58°·0	52°·7	47°·6	38°·0	35°·7
1804	38·0	34·9	37·8	41·4	54·1	59·3	60·3	57·8	55·8	48·4	40·2	34·3
1805	35·7	35·6	41·3	45·8	48·7	55·5	61·1	59·4	56·2	46·0	43·4	36·2
1806	35·1	37·2	39·8	44·9	52·9	58·7	59·3	59·1	54·7	50·3	44·5	39·8
1807	37·3	36·1	34·8	43 5	49·8	55·7	62·4	59·7	47·7	48·8	33·5	36·5
1808	35·9	35·5	39·0	41·1	53·6	58·8	63·3	59·8	53·5	43·1	39·6	35·9
1809	31·2	38·3	41·7	39 9	53·4	55·5	58·3	57·0	53·6	52·3	40·6	36·7
1810	37·3	35·4	35 9	44·0	46·1	58·0	57·4	58·5	54·8	49·5	39·1	35·6
1811	34·2	36·9	42·1	44·4	51·1	55·0	58·8	55·9	53·4	50·7	42·7	36·0
1812	35·6	39·0	35·1	39·1	48·9	55·2	56·1	56·1	53·4	46·9	39·2	35·1
1813	36·0	39·5	42·6	42·7	48·0	56·5	58·6	57·1	53·3	44·1	38·3	37·5
1814	27·7	35·1	37.5	47·6	48·3	53·3	59·0	57·0	54·1	45·0	38·6	35·5
1815	33·5	40·6	41·3	45·0	50·8	55·9	58·2	57·2	53·0	47·6	36·7	33·9
1816	35·3	34·6	36·2	39·6	49·2	54·2	55·3	54·6	50·7	46·1	38·0	35·2
1817	38·2	39 0	37·8	43·6	45·4	54·9	56·8	54·2	53·3	41·6	44·1	35·2
1818	37·0	35·8	36·2	39·3	49·7	59·9	60·2	56·3	52·4	52·4	47·1	39·7
1819	37 8	35·9	40·4	44·0	49·1	54·8	58·5	61·9	53·0	45·6	36·8	33·8
1820	31·7	39·5	38·9	45·9	50·0	54·8	57·9	56·0	51·2	43·6	41·9	38·6
1821	37·2	39·3	39·5	44·8	46·7	53·5	57·2	57·5	53·9	48·4	42·3	39·6
1822	39·3	40·0	41·3	46·0	51·8	59·7	58 6	57·1	50·6	47·5	44·2	37·2
1823	33·5	33·7	38·6	42·6	51·0	54·0	56·3	55·2	52·2	45·2	45·5	37·2
1824	39·7	38·8	38·2	44·8	50·2	55·7	58.9	56·5	53·3	45·4	39·7	37·6
1825	38·2	39·0	40·1	44·6	49·2	56·6	60·9	59·2	56·3	48·8	37·3	38·4
1826	34·0	41·4	39·9	45·3	51·9	62·6	63·0	59·6	53·6	49·1	38·5	40·4
1827	34 9	33·1	37·7	44·2	50·2	56·8	59·7	56·3	55·3	50·3	42·1	42·3
1828	39·1	39·3	41·4	43·8	51·4	58·0	58·7	58·0	54·5	47·9	44·4	43·5
1829	33·0	37·3	38·0	40·7	51·4	57·9	53·0	54·6	49·9	46·6	39·5	37·1
1830	34·8	35·5	42·8	45·9	51·6	54·1	59·1	55·2	52·2	49·2	43·0	35·1
Means,	35·59	37·22	39·12	43·56	50·12	56·40	59·14	57·31	53·16	47·43	40·67	37·13

Mean Temperature of the year, 46°·40.

I do not consider these results to be of a high scientific character, but yet to be so carefully and continuously made as to be well worthy of preservation. I think, also, that the history I have given of the recovery of every particular respecting the observer and the observations, through the testimony of an eye-witness, together with the recovery of the original register and of the original instrument, is a circumstance worthy of note, as an encouragement to trace such data to the best procurable authority.

7. In order to render the observations fit for the purpose for which I had

sought them out—namely, to supplement the deficient years of Mr ADIE's series, I availed myself of the ten years 1821–30, which were common to both series, and by finding the differences of the *uncorrected* Dunfermline temperatures from those of Edinburgh, I used them to deduce for Edinburgh the temperatures of the years 1805–20. This I have more fully explained in my paper on the Climate of Edinburgh.

XIV.—*Description of Asafœtida Plants* (Narthex Asafœtida, Falconer) *which have recently borne Flowers and Fruit in the Royal Botanic Garden of Edinburgh.* By J. H. BALFOUR, A.M., M.D., F.R.SS. L. and E. (With two Plates, XX. and XXI.)

(Read 30th April 1860.)

By means of my correspondents abroad, and more particularly through the kind offices of Dr CHRISTISON, I have been enabled from time to time to cultivate in the Botanic Garden some of the rarer plants of the Materia Medica. Several of these, such as the Jalap plant, the Quassia, and the *Aconitum ferox*, have been already described and figured by me. The present is an interesting addition, and at the suggestion of Dr CHRISTISON I have brought it under the notice of the Royal Society.

Since the time of KÆMPFER, who visited Persia in 1687, Asafœtida has been known to be the produce of an umbelliferous plant. The name is derived from *Asa*, the Persian word for a staff or cane, with the addition of a Latin word indicating its odour. Some suppose that *Asa* is a corruption of the word *Laser* or *Lasar*, used by PLINY to indicate the plant. Several plants have been supposed to yield this article of Materia Medica, and it is probable that it is furnished by at least two distinct species of *Ferula* :—1. *Ferula Asafœtida* of Linnæus, or *Narthex Asafœtida* of Falconer; and 2. *Ferula persica* of Willdenow. Both these plants have been cultivated in this country for some time. Two roots of the latter plant were sent to Edinburgh in 1778, by Dr GUTHRIE of St Petersburg, as the true Asafœtida plant. They had been collected by PALLAS, on the mountains of the province of Ghilan, on the southern border of the Caspian, in the north-west of Persia. Both roots were planted by Dr JOHN HOPE, Professor of Botany, in the open ground of the Edinburgh Botanic Garden. One of them died, but the other bore flowers and fruit. A drawing was made of the plant by Mr FIFE, which was published in the 75th volume of the "Philosophical Transactions of the Royal Society of London," along with a description of the plant by Dr HOPE. *Ferula persica* is figured in "Curtis's Botanical Magazine," plate 2096. The plant has flowered and fruited frequently in Britain. The former species, or the *F. Asafœtida* of Linnæus, had never done so in any part of Europe till the year 1858, when two specimens flowered in the Botanic Garden here. This species was found by KÆMPFER, growing in the province of Laristan towards the Persian Gulf, not far from Gambroon, and near the territory and town of Disguun; and he also states that the plant grows on the eastern confines of Persia, in the province of Khorassan near Herat. KÆMPFER speaks of it as "Umbellifera Levistico affinis, foliis instar Pæonia ramosis; caule pleno, maximo; semine foliaceo, nudo,

solitario, Brancæ ursinæ [Angelicæ] vel Pastinacæ simili; radice asam fœtidam fundente." Since KÆMPFER's time it has been found in various parts of Persia by European travellers. Sir WILLIAM HOOKER, in speaking of the vexed question as to the origin of the various Asafœtidas, says:*—"Referring to our herbarium, we find various plants (varieties, genera, or species), all yielding the Asafœtida of commerce, or an entirely similar gum-resin:—1. Dr FALCONER's *Narthex Asafœtida* (leaves, fruit, and root) from Tibet. 2. A very similar one, collected by Drs FALCONER and THOMSON, in the southern damp valleys of the same mountain (and elsewhere in Kashmire) in whose northern dry valleys FALCONER obtained his Narthex; also, by Dr THOMSON in Piti (Tibet). 3. A flowering specimen gathered in Turkistan by Dr LORD (19th April 1838), and given to Dr FALCONER. 4. Leaves and roots of a quite similar plant sent by Dr STOCKS from Doobund in Beloochistan, as the Asafœtida of commerce. 5. Another similar plant from the banks of the Zenderad, in the Baktiyari mountains of Persia, collected by the late W. LOFTUS (June 7, 1852), of which excellent specimens are in the British Museum. 6. The *Scorodosma fœtidum* of Bunge (characterised generally by the absence of vittæ), collected by M. BORSCZHOW in sandy places on the steppes east of the Caspian, where it attains a height of 9 feet. Of this plant we know the fruit, root, and stems, but not the leaves. BORSCZHOW believes it to be the Khorassan plant of KÆMPFER, and of which fruits are in the British Museum. 7. Imperfect specimens of an oriental umbellifer from Aucher-Eloi and others, which may belong to some of the above."

Among the plants in the Edinburgh Botanic Garden, there is one raised from seeds sent by Mr LOFTUS which resembles the Narthex much in its leaves, but which has not produced flowers. It was received under the name of *Dorema Asafœtida*. The leaves of this plant, in the young state, have no fœtid odour when bruised.

In 1838 Dr FALCONER saw the Narthex growing in a valley to the north of Kashmire, and afterwards cultivated it in the Saharunpoor Botanic Garden. Sir JOHN M'NEILL in 1839, sent home seeds of an Asafœtida plant from Herat. These seeds were given to Dr GRAHAM by Dr CHRISTISON. The Astore seeds were sent by Dr FALCONER himself to the Botanic Garden. All these seeds were sown, and there was some difficulty in saying which of them germinated. The late Mr M'NAB thought that the plants were raised from FALCONER's seeds. The latter says that from an examination of an umbelliferous fruit in the Roylean Herbarium (now at Liverpool), labelled as being the seeds of the wild Asafœtida plant, collected and transmitted by Sir JOHN M'NEILL from Persia, he is disposed to think that it is quite different from Narthex and Ferula, and belongs to another tribe in the order. Through Dr CHRISTISON's kindness, I have obtained specimens of the fruits sent to him by Sir JOHN M'NEILL, as well as those sent by Dr FALCONER

* Botanical Magazine, Description of Table 5168.

(all of which are in the Materia Medica Museum of the University), and on examination I am disposed, with Dr FALCONER, to look upon the former as distinct from the latter. The fruits of the plants in the Botanic Garden agree completely with those sent by Dr FALCONER, and differ somewhat from those sent by Sir JOHN M'NEILL.

In 1840 another locality was found for this Asafœtida plant, by the expedition of Lieutenant WOOD to the sources of the Oxus. This is situated in Syghan near the western termination, and on the northern slope of the Hindoo Koosh range of mountains, about twenty miles north of Bameean. BURNES, in his "Travels into Bokhara," vol. ii. p. 243, says:—"At an elevation of 7000 feet, on Hindoo Koosh, we found the Asafœtida plant flourishing in great luxuriance. It grows to the height of eight or ten feet, when it withers and decays. The milk which exudes is first white, and then turns yellow and hardens, in which state it is put into hair bags and exported. In the fresh state it has an abominable smell, yet our fellow-travellers greedily devoured it."

The seeds sent to the Edinburgh Botanic Garden were carefully reared by the late Mr WILLIAM M'NAB, the superintendent. In 1842 these seeds germinated, but the shoots merely appeared above ground, and then seemed to die. Mr M'NAB, however, did not give them up for lost. He would not allow the earth under the frame to be dug up, and determined to give them another year's trial. Accordingly, next summer new shoots appeared, and from them the stock of plants in the garden has been derived. Ever since that time the plants have sent up a vigorous crown of leaves in early spring, but these have withered by midsummer, and without any symptoms of flowering. The crown of the root, however, continued to increase annually, and in some of the specimens it attained a diameter of four inches or more. Year after year the flowering of the plants was looked for; but this event did not take place till 1858, when two plants which had been transplanted in the spring of 1857 showed, very early in spring, evidence of pushing up a flowering axis. Dr FALCONER, who saw the plants some years before, thought that the delay in flowering might be caused by the too luxuriant growth of the roots, and he suggested that the process might be accelerated by cutting the roots. It is probable that the warm summer of 1857 tended to mature the plants and increase their vigour. The flowering plants did not, as in previous years, produce large radical leaves. The shoots sent up by them consisted entirely of an axis covered by large yellowish-green membranous sheaths, which speedily reached a height of from one to two feet. Flowering branches then began to show themselves in the axils of these sheaths, which are enlarged petioles or pericladia embracing the stems and covering the flower-buds. In the lower part of the axis, the sheaths produced at their extremity pæony-like leaves, much smaller than the ordinary stem leaves. The size of the leaf-laminæ diminished in proceeding upwards; and finally, leafless sheaths were

produced, which became reduced in size, and ultimately disappeared as the terminal umbels were reached. Mr M'NAB furnishes the following particulars:—The plant which flowered in 1858 had been growing vigorously for many years. It had been transplanted on 10th March 1857, and had been protected with glass during winter. On 15th February 1858 it first showed symptoms of flowering, by shooting up a large round ball of a greenish-yellow colour, with a few short leaves rising from it. On the 19th of March the plant had assumed a peculiar club-shaped appearance, twenty-one inches high, and fifteen inches in circumference at the top. This appearance is well seen in some of the photographs taken by my friend Mr W. WALKER, Fellow of the Royal College of Surgeons of Edinburgh. About the 22d of March the sheaths began to unfold themselves, and expose dense clusters of flowers; and at this stage the daily growths became very conspicuous. When it reached the height of about two feet, it was freely exposed to the air, but protected from wind,—and for some time without injury, though the temperature of the night was almost regularly under that of freezing.

The following are the measurements made:—

From 8 A.M. of the	22d	March	to 8 A.M. of the	23d,	growth	4	inches.
Do.	23d	do.	do.	24th	do.	4½	do.
Do.	24th	do.	do.	25th	do.	4½	do.
Do.	25th	do.	do.	26th	do.	3½	do.
Do.	26th	do.	do.	27th	do.	2½	do.
Do.	27th	do.	do.	28th	do.	1½	do.
Do.	28th	do.	do.	29th	do.	5½	do.
Do.	29th	do.	do.	30th	do.	6½	do.
Do.	30th	do.	do.	31st	do.	2½	do.

The upward growth was less marked after this, and at the same time the lateral branches (twenty-nine in number) increased much in length. On 7th April 1858 the plant was 5 feet 7 inches in height, and the branches 36 inches in diameter of spread. The plant attained the height of upwards of 10 feet, and produced abundance of flowering umbels, when it was destroyed by a sudden severe frost on 13th April,—the temperature falling to 22° Fahr. in the night.

An opportunity had been afforded, however, of taking photographs of the plant in its different stages of growth, but unfortunately the fruit was not developed so as to allow of its characters being recorded.

In 1859 other Asafœtida plants produced flowers, and one specimen in particular, which had been planted for five years in the open air, in front of the Orchid House, grew most vigorously. It showed symptoms of flowering at the end of February, long before any of the non-flowering specimens had produced leaves. The flowering axis shot up, as in the former case, from the underground stem, without developing the usual large radical leaves. In order to secure the plant against frost a glazed wooden frame, about 8 feet high, was erected around it, and a connection was established with the adjoining stove, so that a moderate heat might have been supplied in the event of intense frost occurring during night.

This, however, was not necessary. The plant was thus protected from the effects both of very high winds and of cold. On the 13th April, or in about forty-five days, it had attained the height of 7 feet 8 inches. From the 2d to 13th April, the total growth was 30 inches. The first anther was observed fully developed at 11 A.M. on 7th April, and in the course of that day the anthers expanded by hundreds. The plant produced about forty-five compound umbels, some of which were 5 to 6 inches across. The plant progressed well and yielded a large quantity of fruit, which has been partly distributed to botanic gardens in various parts of the country, and has also been sent, by request, to M. DECAISNE, of the Jardin des Plantes in Paris; to M. PLANCHON and M. CHARLES MARTINS, at Montpellier; to Dr REGEL, St Petersburg; and to M. VAN HOUTTE at Ghent. The seeds of this plant germinated freely in the Edinburgh garden in the spring of 1860.

The Asafœtida plant belongs to the Natural Order Umbelliferæ, Section Peucedaneæ, and to the Class Pentandria, order Digynia of LINNÆUS. The plant was referred by LINNÆUS to his Genus *Ferula*, but Dr FALCONER thinks that the character of the vittæ, combined with the obsolete limb of the calyx, and the absence of any involucre are sufficient to constitute a new genus, which he has named *Narthex*, from the word νάρθηξ, applied by DIOSCORIDES to a species of *Ferula* (Dioscord. lib. iii. cap. 75). HOOKER and BENNETT, however, consider the characters of the vittæ of little value, when unaccompanied with others of importance. The former says,—“ The number and length of the vittæ vary extremely in the specimens examined. The habit of the species is entirely the same with that of various Ferulas, which themselves vary greatly in habit and vittæ. We may add, that the individual species or varieties further differ in the smoothness or pubescence of their leaflets, their entire or serrated margins, in the shape of the mericarps, and in the position of the smaller umbels of male flowers, which are often extra-axillary. Plants growing in arid climates (and, like the Narthex, on the borders of moist ones) are eminently variable, both as to sensible properties, form of organs, and habit; and we suspect that the discrepancies between the specimens and descriptions of several of the plants yielding Asafœtida may be attributed to climate.”*

The following are the generic characters,†—*Calycis* margo obsoletus, vel 5-denticulatus. *Petala* oblonga, apice unica inflexa. *Stylopodium*, plicato-urceolatum. *Styli*, reflexi. *Fructus*, a dorso plano-compressus, margine dilatato. *Mericarpia*, jugis primariis 5, 3 intermediis filiformibus, 2 lateralibus obsoletioribus margini contiguis immersis. *Vittæ*, in valleculis dorsalibus plerumque solitariæ (lateralibus nunc 1½—2½ vittatis); commissuralibus 0—6, variis. *Semen*, complanatum. Genus inter Peucedaneas, fructûs vittis magnis, commissuralibusque inæqualibus, et involucro utroque nullo distinctum.

* HOOKER, *loc. cit.*

† FALCONER, in Linn. Trans. xx. 285.

Narthex Asafœtida.—Herba gigantea Tibetica; radice crassa, fibris intertextis rigidis coronata; caule robusto, ramoso; foliis bipinnatis, laciniis lineari-oblongis obtusis, integris vel sinuatis, decurrentibus, glabris vel pubescentibus; petiolis latis, amplis, vaginantibus, ventricosis, interdum aphyllis; umbellis compositis; involucris nullis; floribus flavis, interdum unisexualibus vel sterilibus. It is probably *Asafœtida Disgunensis*, or Hingisèh of KÆMPFER, Amoen. Exot. p. 535. *Ferula Asafœtida*, LINN., Mat. Med. p. 79; D.C. Prod. iv. 173; LINDL., Fl. Med. p. 45.

The plant grows in sunny spots among stones, in the valley of Astore or Hussorah, near the Indus, beyond Kashmire. FALCONER gathered it in fruit near Boosthon, on 21st September 1838. By the Dardohs or Daradri it is called Sip or Süp, and the young shoots are employed as a culinary vegetable.

The following description is taken from the plants which were grown in the Botanic Garden,—Herbaceous plants attaining a height of between 9 and 10 feet, and giving out a strong alliaceous odour when any part is bruised. Flowering stem erect, terete, striated, about a foot in circumference at the base, giving off flowering branches bearing compound umbels. After the plant flowers and fruits it dies, but the period of flowering is often long delayed. In the case of the plants in the Botanic Garden it was postponed for sixteen years. It is therefore a monocarpic plant, with the period of flowering indefinite. The cotyledons are linear, from 2 to 2½ inches in length. The roots are large and thickened, fusiform, dark-coloured externally, and white within, about a foot and a half in length, and about a foot in circumference at their thickest part, exhaling a very strong and enduring asafœtida smell. Some of them were laid for a few weeks in a room last year, and, although removed five or six months ago, the odour still remains. The crown of the roots is covered with a mass of fibrous matter. During the first year of growth, the root attains the thickness of the thumb. It continues to increase annually, and sometimes attains the thickness of a man's calf, or even his thigh. The radical leaves, which are the only ones produced on non-flowering specimens, are about 18 inches in length, but in flowering specimens they are smaller; they are bipinnately cut, and have a pæony-like appearance; the segments are linear, ligulate, and obtuse, entire or sinuately lobed. The lower leaves in the fruiting plant had compound laminæ 13 or 14 inches long, borne on evident rounded petioles, which, at the base, had short sheaths, nearly surrounding the whole stem; the lowest four leaves did not bear umbels in their axil; all the rest did. In proceeding upwards on the flowering stem, the laminæ diminished in size, while the sheathing part of the petiole or the pericladium increased—the laminæ becoming 3½ or 4 inches long, the sheaths 7 to 9 inches in length by 8 in breadth. In the upper part of the axis the sheathing petiole represents the whole leaf; and the sheaths near the top are reduced to abortive membranous scales, about 1 inch in length, and finally disappear, when the umbels at the summit are reached. The large sheathing inflated petioles gave a peculiar character to the plants.

The petioles divided in a trifurcate manner. From the axils of the petioles compound umbels were produced. The largest flowering branch was 19 inches long, and the others varied from 6 to 12 inches. The umbels had neither involucre nor involucel. The rays of the general umbels varied in length from 2 to 2½ inches, and in number from thirty to fifty. Besides the fructiferous umbels, there were others below them which appeared first in a globular form, and the flowers of which were unisexual, usually male, and sterile. The peduncles bearing these barren umbels were very long, and they sometimes exhibited small bractlets at their base. Similar bractlets were seen occasionally on the other peduncles. The limb of the calyx was obsolete—a mere rim with five slight projections or denticular points; petals yellowish, somewhat ovate, entire, one of them with the point inflexed. In the barren flowers, the petals were oblique and unequal, and acute at the apex. Stylopode urceolate and plicate, with a sinuous margin. Styles filiform, at length recurved and deflexed. Fruit, with single vittæ in the dorsal valleculæ; occasionally in the lateral valleculæ the vittæ were more than one, and divided.

The Asafœtida plant grows in a very dry climate. Besides the gum-resin, FALCONER states that the fruit of Narthex is imported into India from Persia and Affghanistan under the name of Anjoodan, being extensively employed by the native physicians of India. Anjoodan or Andsjudaan and Halteet are the terms applied to the seed of Heengseh or Hingiseh by AVICENNA, and used by the Indo-Persians and Arabic writers generally in describing the Asafœtida plant.

The gum-resins procured from umbelliferous plants were in high repute in ancient times, and they are noticed by ancient authors. One of these is Galbanum, the Chelbenah of Scripture, used for compounding various ointments; another, Opoponax, the produce of a plant called Πάνακες Ἡράκλειον, by DIOSCORIDES; a third, is Sagapenum, described by the same author as being furnished by a species of *Ferula*; a fourth is Ammoniacum, yielded by a plant called Agasyllis; and a fifth is the gum-resin, now under consideration.* There was also a gum-resin, called by the Greeks ὀπος κυρηναϊκὸς, or Cyrenaic juice, which appears to have been the produce of an umbellifer called *Thapsia Sylvium*. PLINY, in referring to this says, "Laserpitium, quod Græci Σιλφιον vocant, in Cyrenaica provincia repertum; cujus succum vocant Laser."† There appears, however, to have been another Laser; for PLINY says, "Diuque jam non aliud ad nos invehitur Laser, quam quod in Perside aut Media et Armenia nascitur large, sed multo infra Cyrenaicum." This Laser of Persia is by some supposed to be the Asafœtida. AVICENNA, in his "Canon Medicinæ," says, that there are two species of Asa or Laser, "quarum una est fœtida, et alia est odorifera non fortem habens odorem."‡

* Dioscorides lib. iii. c. 94, 95, 97, 98.

† PLIN. Nat. Hist. xix. c. 15.

‡ AVICENNA, lib. ii. tract 2, c. 53.

Asafœtida is got by incision, cuts, and slices, taken from the top of the root of Narthex. The stem yields also a milky juice, which, when allowed to flow, concretes into clear tears, having a very strong fœtid and enduring odour. The whole plant, especially when bruised, exhales a strong garlic odour. The smell of the flowers, when expanded, is of a sweetish honey-like nature, resembling that of *Galium verum*. The ripe fruits have the asafœtida odour when bruised, and retain it at least for eighteen years. Nevertheless, the cotyledons and early leaves of the growing young plant are not fœtid, although they contain a milky juice. The young root has a bitterish taste.

DESCRIPTION OF THE PLATES.

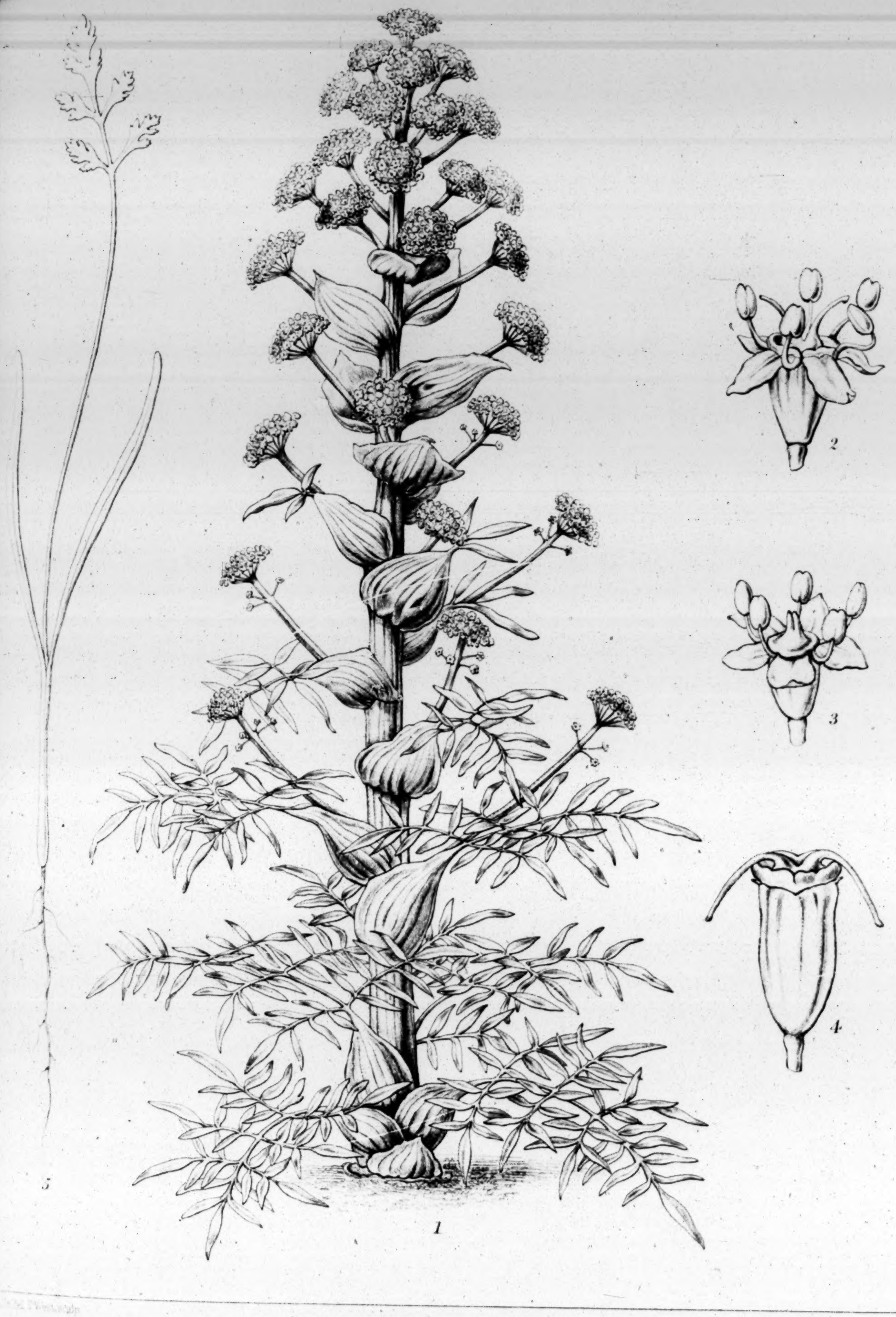
Plate XX.

Narthex Asafœtida, Falconer.

Fig. 1. Plant of *Narthex Asafœtida* much reduced in size, showing ventricose sheathing petioles or pericladia, bearing pinnately-divided laminæ, and giving origin to numerous compound umbels. Fig. 2. Perfect flower, with adherent calyx, having an obsolete 5-lobed or 5-toothed limb, five oblong yellow petals, one of them having an inflexed point, five stamens, an epigynous disk, and two styles slightly recurved. Fig. 3. Sterile male flower, having five stamens and a rudiment of the pistil, with unequal and somewhat ovate yellow petals. Fig. 4. Ovary, with epigynous limb of calyx, which exhibits five denticular points; disk, and two recurved and deflexed styles. Fig. 5. Young germinating Asafœtida Plant, with two linear cotyledons and primordial leaf.

Plate XXI.

Fig. 1. Portion of hollow stem of *Narthex Asafœtida*, bearing an amplexicaul inflated petiole or pericladium which is terminated by a pinnately-divided lamina, and gives origin to a peduncle with a large fertile compound umbel, and three smaller rounded unisexual or sterile ones. Fig. 2. Cluster of Cremocarps or Diachænia. Fig. 3. Mericarps magnified, showing dorsal and commissural surface. The margins are winged, and the juga are represented, with the valleculæ and vittæ. Fig. 4. Transverse section of a mericarp, showing winged margins, valleculæ, vittæ, juga, and albumen.



W. West imp.

NARTHEX ASAFOETIDA. *Falc.*

Fig: 1. Plant of Narthex Asafoetida much reduced in size, showing sheathing pericladia, leaves and umbels. Fig: 2. Perfect flower, showing adherent calyx, oblong petals, one having an inflexed point, stamens, epigynous disk, and 2 styles slightly recurved. Fig: 3. Male flower with rudiment of the pistil. Fig: 4. Ovary with denticulate epigynous limb of calyx, & 2 recurved and deflexed styles.

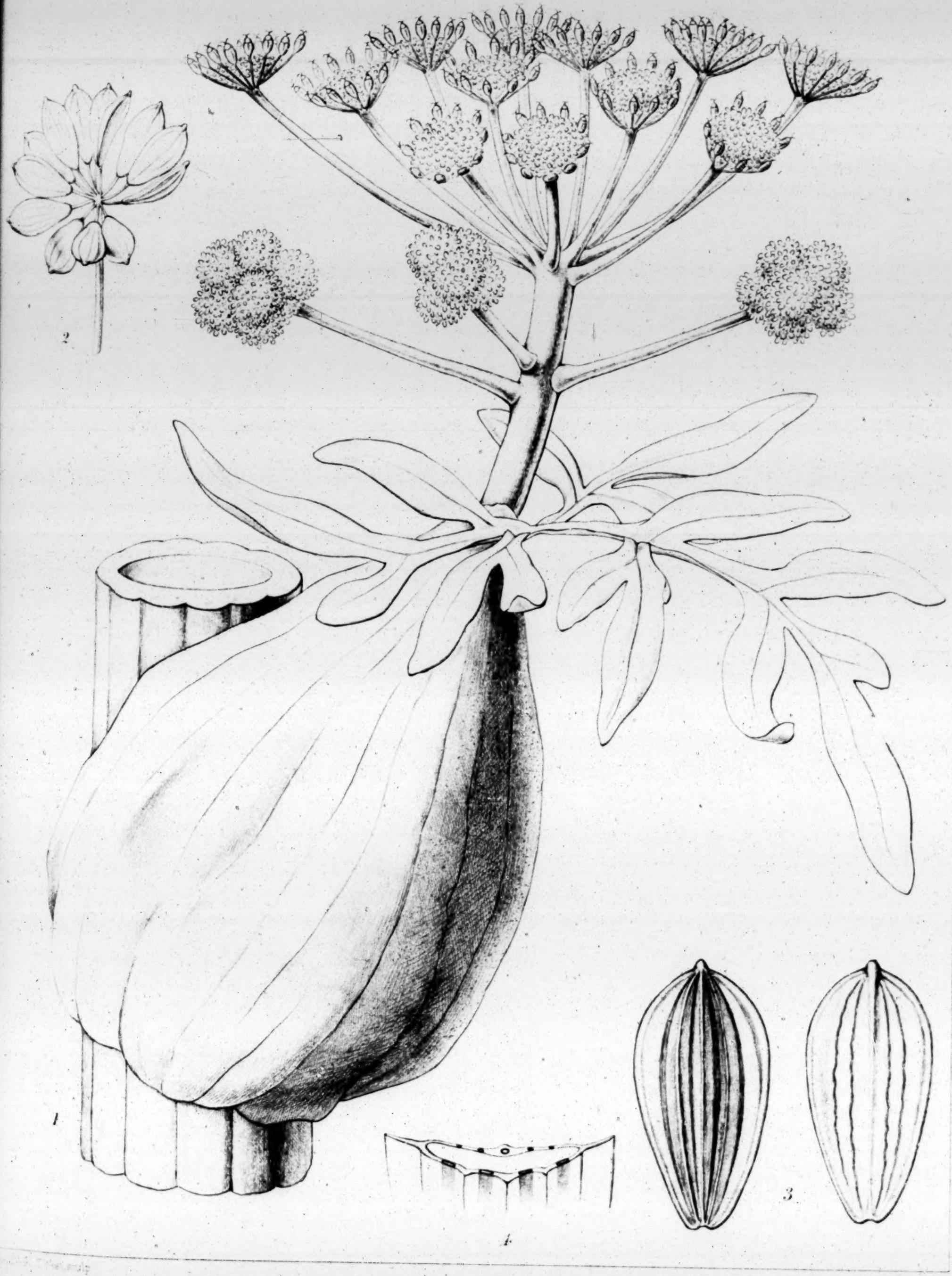


Fig.1. Portion of stem of Narthex Asafoetida, bearing an amplexicaul inflated petiole or perulanium, which is terminated by a divided lamina, and also bearing a peduncle with a fertile compound umbel, and 3 smaller rounded unisexual or sterile ones. Fig: 2. Cluster of fruit or cremocarps. Fig. 3. Fruit or cremocarps magnified, showing winged margin & juga with valleculae & vittae. Fig. 4 Transverse section of pericarp showing winged margins, valleculae, vittae, juga & commun.

XV.—*On the Constitution of Oil of Cajeput.* By MAXIMILIAN SCHMIDL, Assistant to Professor ANDERSON in the Laboratory of Glasgow College.

(Read 17th April 1860.)

The constitution and properties of the essential oils attracted considerable attention during the earlier period of the investigations in organic chemistry, and several of them have contributed in no small degree to the development of the general doctrines of that department of the science. A majority of these substances, however, may be said to be still almost unknown, all the information we possess regarding them being restricted to a single analysis, made on what was obviously a mixture, or to a few observations of a general and often indefinite character. The complex nature of many essential oils, and the want of experience and easy processes for the separation of their constituents, have hitherto deterred chemists from attempting their minute examination, but the progress of the science has increased our knowledge of the methods of investigating these substances, and renders it important that their true constitution and position in the chemical system be definitely fixed. With this object I have taken up the investigation of Oil of Cajeput; our information regarding which is confined to a single analysis made by BLANCHET and SELL, some five and twenty years ago.

Oil of Cajeput is prepared in the East Indies, by distilling along with water the leaves of *Melaleuca Leucadendron;* it was formerly used to a great extent as an external and even internal medicine, but has now become more or less obsolete, and is seldom met with in a pure or unchanged state, except in the hands of wholesale druggists. As introduced into Europe, it possesses a light-green colour resembling a dilute solution of chloride of chromium, which is caused by a resinous colouring matter dissolved in it, but in so small a proportion, that I have hitherto failed to obtain it in sufficient quantity and pure enough for elementary analysis. I suspected, in common with other observers, that this coloration might be due to a salt of copper; but although I always detected this metal in the crude oil, by treating it with nitric acid, when, after its total destruction, the blue nitrate of copper was left behind, or by the still simpler process of passing sulphuretted hydrogen through the oil, when a black precipitate of sulphuret of copper was immediately formed; I nevertheless satisfied myself that it possessed a green colour of its own; since, after the removal of the sulphuret of copper, it exhibited the same appearance, and, on distillation, the latter fractions which passed over had a decided green colour, which could not be due to any salt of copper, as none of its compounds volatilise at the temperature at which these fractions distilled; nor

could I then by any reagent or operation detect the presence of copper, as I did in the crude oil.

The fact, however, that copper almost invariably is found in the crude commercial article, can only be accounted for, either by the use of a copper head in the distilling apparatus of the Indians, or by intentional adulteration employed in order to preserve the green colour of the oil, which it otherwise, as I have convinced myself, loses when in process of time oxidation takes place, in consequence of which a reddish brown colour is produced, which is said to make the article, for medicinal purposes, less saleable.

The Specific Gravity of the Crude Oil at 10° C.=0·926.—It does not solidify at −25° C.; its taste is pungent and aromatic; its smell only pleasant when diluted, but very disagreeable when concentrated; it is soluble in all proportions in alcohol and ether. When submitted to distillation, it becomes turbid at 120° C., and acquires a yellowish brown colour; at 175° C., it commences to distil over, and before the thermometer indicates 178°, nearly two-thirds of the oil have passed over, the fluid collected being limpid and perfectly colourless; from 178° to 250° C. the mercury rises gradually, without showing any distinct boiling points. The fluid passing over between this long interval changes gradually from a pale yellowish colour into darker shades, approaching always more and more to green, until at last the fraction between 240° to 250° C. becomes of a dark untransparent green colour.

At 265° C. the retort is almost dry, retaining some metallic copper mixed with carbonaceous and resinous matter, which, when treated with ether, imparts to this reagent a green colour, and on evaporation of the latter a green resin is left behind, which is soluble in the rectified fraction (boiling at 175° C.), and thereby able to restore the coloured appearance of the original oil.

Whether the fractions beyond 178° C. be special and pre-existing constituents of the crude oil, or mere products of decomposition, and therefore of changeable character, I am as yet not able to state, since the results of operations performed with them are either contradictory as to this effect, or not yet sufficient to countenance the one or the other of these opinions; but still, in the course of time, and in a second paper, I hope I will be able to give some satisfactory accounts about them.

Most of my operations are therefore confined to the first large fraction, boiling at 175° to 178° C.; in particular cases, however, which I shall endeavour to specify, the crude oil has been employed.

I. Bihydrate of Cajputene, $C_{20}H_{16}+2HO$.

I commenced my experiments by agitating the rectified fraction with bisulphate of soda, by means of which I satisfied myself of the absence of aldehydes and other bodies, capable of combining with that substance. And as, from the

fixed boiling point, there could be no doubt that this fraction consisted only of one substance, I at once proceeded to its elementary analysis, after having had it rectified four times, and well dried over chloride of calcium. The following are the detailed results:—

(a) 2·60 grains of substance gave	. . .	7·42 CO_2	2·79 HO.
(b) 3·29 „ „	. . .	9·22 CO_2	3·48 HO.

	A.	B.		
Carbon,	77·83	77·86	77·92	Theory.
Hydrogen,	11·92	11·91	11·68	
Oxygen,	10·25	10·23	10·40	
	100·00	100·00	100·00	

These results agree with those of Messrs Blanchet and Sell,* who found Oil of Cajeput to consist of 77·92 carbon, 11·69 hydrogen, and 10·39 oxygen, to which they applied the name of Hydrate of Dadyl.

In order, therefore, to fix its rational formula, I then proceeded to determine its vapour density, of which the following are the details:—

Temperature of air,	14° C.
Temperature of vapour,	85° C.
Excess of weight of balloon,	0·580 grm.
Capacity of balloon,	200·00 C.C.
Residual air,	...
Density of vapour	5·43

The formula $C_{20}\ H_{16}\ 2HO$ requires—

20 volumes of carbon,	$20 \times 0{\cdot}831$	$= 16{\cdot}620$
18 „ hydrogen,	$36 \times 0{\cdot}0693$	$= 2{\cdot}490$
2 „ oxygen,	$2 \times 1{\cdot}050$	$= 2{\cdot}100$
		21·21

$21{\cdot}21 : 4 = 5{\cdot}30$ theoretical result.

From the close agreement of the experiment with the theory, I could not hesitate to represent Oil of Cajeput by the formula $C_{20}\ H_{18}\ O_2$; and, induced by reactions of the substance, to be mentioned hereafter, I assigned to it the name of Bihydrate of Cajputene,† thereby indicating its resemblance with Oil of Turpentine, in comparison with which it possesses (besides $C_{20}\ H_{16}$) two additional equivalents of water.

Physical and Chemical Qualities and Reactions of Bihydrate of Cajputene.

The specific gravity of this substance at 17° C. is = 0·903; it boils constantly at 175° C., and is soluble in all proportions in oil of turpentine, alcohol, and ether.

* Annalen der Pharmacie, vii. 162.

† In order to avoid long words I write Cajputene and not Cajeputene, thus rendering the "j" half mute like "i."

When exposed in a moist state for a considerable time to atmospheric air, it changes into a reddish fluid, showing at last a pretty strong acid reaction to litmus paper.

In contact with an aqueous solution of potash a soluble salt is formed, the acid of which is precipitated by hydrochloric or sulphuric acid as a resinous substance.

When dropped into melted potash, a compound is formed which is soluble in water and decomposed by a strong inorganic acid; the precipitate being also a resin.

When treated at high temperature with sodium, a crystalline mass is produced, which is soluble in water and alcohol, and consists of soda and an organic substance; the latter being likewise separable by strong acids (organic and inorganic), as a resin of a very agreeable smell.

If the vapours of the oil be passed through a combustion tube filled with soda-lime and maintained at a red heat, an oily product is formed, which is obtained in a receiver suitably connected with the tube. This product possesses a peculiar smell, entirely different from that of the original substance, and a bright yellow colour; the soda-lime itself is thoroughly blackened with charcoal, and on the addition of an acid, it evolves copiously carbonic acid, thereby indicating that some decomposition must have taken place in the oil when passing through the tube; the analyses of the changed product will follow afterwards.

Bihydrate of cajputene does not seem to be changed when digested with peroxide of lead.

If the oil be distilled over permanganate or bichromate of potash in the presence of dilute sulphuric acid, a thick resinous fluid is produced.

Fuming nitric acid acts very violently on the oil, red fumes of nitrous acid being evolved even in the cold, and an abundance of oxalic acid being formed. Commercial nitric acid produces the same effect at boiling temperature; at ordinary temperature, however, it acts slowly, converting the oil into a thick red fluid.

Fuming sulphuric acid entirely changes the molecular condition of the oil, even if the latter be kept during the operation immersed in ice, a thick brown fluid being formed, which boils beyond 360° C.

Commercial sulphuric acid acts at low temperature very slowly on the oil, so, that after four or five hours little or no change is observed if the acid be removed and the oil well washed; but if the temperature be allowed to rise, either by artificially employed heat, or by continued unchecked chemical action, sulphurous acid is given off, blackening of the oil commences, and may even go on to total destruction of the substance. This can be avoided by caution, and then a sulpho-compound will be formed, which gives with baryta a soluble salt.

Dilute sulphuric acid acts most curiously on the oil, since, in the opposite manner to the fuming and commercial acid, it not only does not deprive the oil of its two equivalents of water, but causes the formation of a crystalline substance which possesses four equivalents of water in addition to the two original ones.

Anhydrous phosphoric acid deprives the oil of its two equivalents of water, when heated along with it.

Chloride of zinc, under similar circumstances, does not act so energetically, the two equivalents of water having been found to have been only partly removed from the oil after the application of that reagent.

Commercial hydrochloric acid, if left in contact for some weeks with the crude oil, produces a crystalline compound. Gaseous hydrochloric acid produces, under particular circumstances to be mentioned below, two kinds of crystalline compounds.

Chlorine, when passed through the oil, raises its temperature to a considerable height, producing, however, no visible change in it.

Iodine dissolves in the oil, and, under precautions which will be further described, different crystalline compounds may be formed.

Bromine acts very briskly, and produces under similar circumstances, like iodine, crystalline compounds.

Before leaving the Bihydrate of Cajputene, I will briefly note the results of the analyses performed with that secondary product, which was obtained when the first large fraction had been passed through red-hot soda-lime.

Fraction 180° to 185° C.

(*a*) 2·49 grains of substance gave, ...	7·29 CO_2	4·25 HO.
(*b*) 4·15 „ „	12·18 CO_2	4·51 HO.

	A.	B.
Carbon, ...	79·76	80·03
Hydrogen, ...	12·20	12·07
Oxygen, ...	8·04	7·90
	100·00	100·00

The increase of carbon and hydrogen shown by these analyses on the one hand, and the presence of a large amount of charry matter and carbonic acid in the employed soda-lime on the other, indicate sufficiently that by that operation some change or another must have taken place in the oil; but as I have not yet entered upon any investigation of this product, further than the above analyses, I refrain from giving any other opinion about it, except that the above results would best correspond with the empirical formula $C_{26}\ H_{24}\ O_{20}$, the percentages of which are—

79·59 C.
12·44 H.
7·97 O.
100·00

Since I succeeded in obtaining a crystalline iodine compound, and a hydrate of

this secondary product, I hope to be able to give some further and more satisfactory results about it in a subsequent paper.

II. Monohydrate of Cajputene.—$C_{20}\,H_{16}+HO$.*

The crude oil is raised to its boiling point in a deep open vessel, and when commercial sulphuric acid is continuously dropped into it, violent ebullition—which after a short time is accompanied by a peculiar crackling sound—takes place. As soon as this is observed the flame is lowered, and the acid very cautiously added, until almost suddenly the fluid assumes a dark colour, which goes on in one moment from the surface throughout its whole depth. Should this be overlooked, and the acid indiscriminately added, the process goes on further than desired, sulphurous acid is formed, both equivalents of water removed, and the products become very complicated. At the moment, therefore, when the darkening of the substance just commences, the vessel must be removed from above the flame and allowed to cool. The upper oily fluid is then separated from the acid, well washed and distilled. Amongst the fractions obtained thereby, I chose that which passed over at 170° to 175° C., as having been the largest; and after several rectifications, I proceeded to ascertain its composition, and to determine the density of its vapour, of which the following are the details:—

(a)	3·75 grains of substance gave, . .	11·38 CO_2	4·00 HO.
(b)	3·45 „ „ . .	10·47 CO_2	3·59 HO.
(c)	2·04 „ „ . .	6·18 CO_2	2·180 HO.

	a	b	c	Theory.
Carbon, . .	82·73	82·79	82·62	82·75
Hydrogen, . .	11·85	11·59	11·87	11·72
Oxygen, . .	5·42	5·62	5·51	5·53
	100·00	100·00	100·00	100·00

Vapour Density.

(1.)	(2.)	(3.)
Temperature of air, 18° C.	Temperature of air, 10° C.	Temperature of air, 20° C.
Temperature of vapour, 220° C.	Temperature of vapour, 210° C.	Temperature of vapour, 200° C.
Excess of weight, 0·404 grm.	Excess, 0·405 grm.	Excess, 0·520 grm.
Capacity, 159·5 CC.	Capacity, 158·4 CC.	Capacity, 214 CC.
Residual air	Residual air, 2 CC.	Residual air, 14. CC.
		Barometer, 750 M.M.
D=5·19.	D=5·26.	D=5·27.

* Since April last, the time when the present paper was read before the Royal Society, I undertook, at the suggestion of several professional friends, to prepare anew the substances under consideration. The results arrived at now, by repeated combustions and determinations of its vapour density, showing nowhere a difference of much more than one-tenth, if compared respectively with one another, or with those obtained previously, leave really little or no doubt at all about the purity and chemical unity of the substance—however novel, singular, and exceptional it may seem, that the vapour of a body containing one atom of oxygen should condense to four volumes. However, as the substance is easily prepared, the experiment should be repeated by others, and not only with Oil of Cajeput, but with all the bihydrates of the turpentine-radical. Like experiments with bodies of ana-

The formula, $C_{29}\ H_{17}\ O$, requires—

20 volumes of carbon		$= 20 \times 0{\cdot}831$	$= 16{\cdot}620$
17 „	hydrogen	$= 34 \times 0{\cdot}0693$	$= 2{\cdot}356$
1 „	oxygen	$= 1 \times 1{\cdot}108$	$= 1{\cdot}108$
			$20{\cdot}090$

$$20{\cdot}09 : 4 = 5{\cdot}02.$$

III.—Cajputene, Isocajputene, Paracajputene—$C_{20},\ H_{16}$.

The rectified oil is allowed to cohobate over anhydrous phosphoric acid for about half an hour; on entire distilling, an oil passes over, which by repeated rectification separates into three principal fractions of distinct and steady boiling points.

Cajputene is one and the first of these fractions; it passes over at 160° to 165° C. It is perfectly colourless, and possesses a very pleasant smell, resembling that of hyacinths; it is insoluble in alcohol, soluble in ether and oil of turpentine; its specific gravity at 15° C. = 0·850.

The following are the details of its analysis:—

(*a*)	3·20 grains of substance gave	10·36 CO_2	3·43 HO.
(*b*)	3·90 „ „	12·63 CO_2	4·10 HO.

	a	*b*	Theory.
Carbon,	88·29	88·34	88·24
Hydrogen,	11·91	11·78	11·76
	100·20	100·12	100·00

Vapour Density.

Temperature of air,	16° C.
Temperature of vapour,	204° C.
Excess of balloon,	0·399 grm.
Capacity of balloon,	165 CC.
Residual air,	7 CC.

D=4·717.

The formula requires ·465.

Reactions.

If Cajputene is exposed to a current of gaseous hydrochloric acid, a beautiful violet fluid is produced; but no crystalline compound is deposited, even if the oil be maintained during the operation at −10° C, and preserved afterwards for any length of time. A mixture of commercial nitric and sulphuric acid acts very vio-

logous composition will probably increase the number of similar instances. Further remarks as to its reactions, physical qualities, secondary products, and its relation to the Bihydrate of Cajputene, compared with which it might prove to be an analogous ether, I will endeavour to give in a subsequent paper.

lently on Cajputene, producing a yellow brittle resin. Bromine, also, acts very briskly in contact with it, producing a dark viscid oil. Iodine behaves indifferently at ordinary temperature towards it; but at a raised temperature hydrogen is copiously evolved, and a black fluid produced. Cajputene resists the influence of atmospheric air, retaining its peculiar smell and colourless appearance even after a very long exposure to this generally powerful agent.

Isocajputene is the second fraction, separated from that oily product obtained by the action of anhydrous phosphoric acid; it passes over at 176° C. to 178°; its specific gravity at 16° C. is = 0·857; it is insoluble in alcohol, and mixes in all proportions with ether and with oil of turpentine; its smell is different from and less agreeable than that of Cajputene, and when exposed to atmospheric air it soon acquires a yellow colour, and a more pungent aromatic smell.

The same body may be procured by continued action, at a raised temperature, of commercial sulphuric acid upon the Bihydrate of Cajputene, especially if the oil be distilled along with the acid.

The following are the details of the analyses performed:—

(1.) *Product got by the Action of Phosphoric Acid.*

(*a*) 2·24 grains of substance gave 7·24 CO_2 2·35 HO.
(*b*) 2·70 " " 8·72 CO_2 2·84 HO.

	a	*b*	Theory.
Carbon, . . .	88·16	88·18	88·24
Hydrogen, . . .	11·64	11·68	11·76
	99·80	99·86	100·00

(2.) *Product got by the Action of Sulphuric Acid,*

(*a*) 4·20 grains of substance gave 13·56 CO_2 4·50 HO.
(*b*) 2·93 " " 9·48 CO_2 3·12 HO.

	a	*b*
Carbon, . . .	88·05	88·23
Hydrogen, . . .	11·90	11·83
	99·95	100·06

Vapour density of (1.) = 4·82; of (2.) = 4·52; theory = 4·65.

Nitro-sulphuric acid, gaseous hydrochloric acid, bromine, and iodine react in the same way on Isocajputene as on Cajputene. Commercial and even dilute sulphuric acid, dilute nitric, and dilute hydrochloric acid, all of which behave indifferently towards Cajputene, react upon Isocajputene, producing by mere contact, in a very short time, dark viscid fluids.

Paracajputene, C_{40} H_{32}, is the last fraction of those isomeric hydrocarbons produced by the action of anhydrous phosphoric acid; it distils at 310° to 316° C.; is very viscous, and of lemon-yellow colour, but if looked at in certain directions, it shows a beautiful deep blue fluorescence. It is insoluble in alcohol and oil of turpen-

tine, but soluble in ether, and when exposed to atmospheric air, it rapidly oxidises, acquiring a red colour and resinous consistence.

Analyses.

(a) 4·19 grains of substance gave 13·57 CO_2 4·55 HO.
(b) 3·15 „ „ 10·19 CO_2 3·42 HO.

	a	b
Carbon	88·33	88·28
Hydrogen	12·06	12·06
	100·39	100·34

Vapour Density.

Temperature of air,	16° C.
Temperature of vapour,	320° C.
Excess of weight of balloon,	0·599 grm.
Capacity of balloon,	198 CC.
Residual air,	22 CC.

$$D = 599 + \left(\frac{198 \times 0{\cdot}0001224}{176 \times 0{\cdot}000605}\right) = \frac{84135}{10168} = 7{\cdot}96.$$

The theory requires double the quantity of what is required for the formula $C_{20} H_{16} = 4{\cdot}65 \times 2 = 9{\cdot}30$. The great difference between the experimental and theoretical results can only be accounted for by the high boiling point of the substance, and its great tendency to decompose at that temperature.

Reactions.

Gaseous hydrochloric acid produces a dark violet fluid, which does not deposit any crystalline compound, even if the operation be performed at −10° C. Nitro-sulphuric acid does not act so violently as on the two foregoing fractions.

IV. Hexhydrate of Cajputene, $C_{20} H_{16} + 6$ HO.

Two parts of dilute sulphuric acid are added to one of the crude Oil of Cajeput; the mixture is then well shaken for several days, until the watery layer acquires a yellowish colour; thereby the presence of organic matter in the latter is indicated. After that the mixture is left to itself, when, usually from about the tenth day and upwards, crystalline tufts, adhering to the sides of the vessel, are found.

These crystals are sparingly soluble in cold, but readily in boiling alcohol; they fuse at 120° C., and solidify again at 85° C. When submitted to dry distillation, the oily fluid which passes over solidifies again in the colder parts of the receiver; but from the limited amount of substance then at my disposal, I could not ascertain if this product of sublimation was of the same or of altered composition.

The following are the detailed results of the analyses performed with the substance after previous recrystallisation out of alcohol:—

(a) 2·65 grains of substance gave 6·17 CO_2 2·86 HO.
(b) 2·61 " " 6·04 CO_2 2·61 HO.
(c) 2·98 " " 6·90 CO_2 3·21 HO.

	a	b	c	Theory.
Carbon,	63·39	63·11	63·11	63·15
Hydrogen,	11·99	11·96	11·92	11·57
Oxygen,	24·62	24·93	24·97	25·28
	100·00	100·00	100·00	100·00

Crystals of the same composition I found deposited in a secondary fraction of the crude oil, which on distillation passed over at 210°–230° C., and was left for a very long time moist and exposed to the action of atmospheric air. When the crude oil is mixed with dilute nitric acid and alcohol in the same proportions as are used when a similar compound is contended for in oil of turpentine, no crystals are found before at least seven or eight months; after the lapse of this time, however, such appear and are seen suspended in the oil, which meanwhile changes into a heavy black fluid. The quantity which I got by this method was so small, that I was not able to carry out any operations with it in order to satisfy myself if its composition and qualities really were the same with, or different from, the above-mentioned Hexhydrate of Cajputene; but as I am again preparing the same substance just now, I hope to give some account of it in a second paper. There also I intend to describe other crystalline compounds which I just recently obtained, by the action of dilute nitric acid upon the total crude oil, upon the rectified fraction, boiling at 175° C., upon the second fraction, boiling from 178°–200° C., and upon the last green fraction, boiling from 200°–255° C. By the comparison of these crystalline substances I may perhaps become enabled to state something more satisfactory about the nature of those secondary fractions of the crude oil.

V. Hydrochloro Compounds of Cajputene.—*Bihydrochlorate of Cajputene*, $C_{20} H_{16} + 2 HCl$.

If gaseous hydrochloric acid be passed through the rectified oil, which is maintained at low temperature, a violet fluid is produced, which, after 10–15 minutes, suddenly solidifies into a crystalline mass, so that the orifice of the delivery-tube becomes obstructed, thereby preventing the further application of the gaseous acid. This crystalline compound, however, I was unable to analyse, since no sooner was it removed from the vessel where prepared than it deliquesced, even when pressed between bloating paper, which by means of artificial cold had been maintained at −25° C.; the fluid, also, resulting from that deliquescend substance, gave off constantly fumes of hydrochloric acid, and on distillation it decomposed entirely, showing no constant boiling point. If, however, immediately after the application of gaseous hydrochloric acid, that crystalline mass be thrown

into a vessel containing water or alcohol, beautiful long prisms are formed after a few days, which contain no chlorine, and seem to be of the same composition as the Hexhydrate of Cajputene.

If the oil be mixed with a third of its volume of alcohol, or if, in place of alcohol, strong aqueous hydrochloric acid be taken, and gaseous hydrochloric acid then passed through either of the mixtures, a crystalline compound is formed which is of steady constitution, and different in all its physical and chemical qualities from the one formed without the presence of alcohol or aqueous hydrochloric acid.

The following are the detailed results of its elementary analyses :—

(*a*) 0·266 grm. of substance gave 0·562 CO_2 0·214 HO.
(*b*) 0·268 " " 05·65 CO_2 0·216 HO.
(*c*) 0·145 " " 0·205 AgCl.

	a	*b*	*c*	Theory.
Carbon,	57·61	57·54		57·41
Hydrogen,	8·93	8·95		8·61
Chlorine,			34·49	33·98
				100·00

Bihydrochlorate of Cajputene melts at 55° C., and solidifies again at about 30° C.; when submitted to dry distillation, it gives off fumes of hydrochloric acid at 60° C., and splits into several fractions, one of which is of constant boiling point and steady chemical composition, which will be mentioned afterwards. When boiled with an alcoholic or aqueous solution of potash it undergoes no change, unless a high temperature be maintained for a long time by cohobation, when one equivalent of hydrochloric acid is removed. It is sparingly soluble in cold, but readily soluble in boiling alcohol and in ether; it possesses no taste or smell whatever, and differs in that and in most of its other physical and chemical qualities from the isomeric compound in oil of turpentine, called the artificial camphor; out of alcohol it crystallizes in beautiful radiating tufts.

VI. Monohydrochlorate of Cajputene, $C_{20}H_{16} + HCl$.

When the Bihydrochlorate of Cajputene is submitted to distillation, amongst several other fractions, one passes over which has been mentioned before as possessing a constant boiling point. This fraction distils at 160°, and its analyses gave the following results :—

(*a*) 0·330 grm. of substance gave 0·848 CO_3 0·295 HO.
(*b*) 0·257 " " 0·654 CO_2 0·233 HO.
(*c*) 0·172 " " 0·143 chloride of silver.

	a	*b*	*c*	Theory.
Carbon,	70·00	69·40		69·76
Hydrogen,	9·93	10·07		9 88
Chlorine,			20·53	20·36
				100·00

A product of similar composition is obtained when the Bihydrochlorate of Cajputene is treated for several days at high temperature with an aqueous or alcoholic solution of potash; the smell of this substance, however, is so entirely different from that of the other monohydrochlorate (reminding of pelargonic ether), that some further investigation may probably lead to more striking chemical as well as physical differences between these two isomeric substances.

VII. Bichloride of Cajputene, $C_{20} H_{16} + 2Cl$.

The large rectified fraction of Oil of Cajeput is mixed with some very dilute nitric acid, and then exposed to a stream of gaseous hydrochloric acid, when, after a few minutes, violent evolution of yellow and red fumes, consisting of chlorine and nitrous acid, takes place. The gaseous hydrochloric acid is allowed to pass so long till the oily fluid in the vessel has entirely sunk to the bottom, having then the watery layer (reversely to the beginning of the operation) above itself.

If the vessel be, after the operation, kept at a low temperature, a crystalline compound may be formed, which, however, I was only once fortunate enough to obtain, but in so small a quantity that I could not make more than one analysis of it, by means of which, however, I convinced myself of the presence of chlorine in that substance. In ordinary cases, therefore, I had to content myself with a limpid brown fluid, which, in consequence of the adhering nitric and nitrous acid, I redistilled over a strong solution of potash; and thus prepared I submitted it to its elementary analyses, of which the following are the detailed results:—

(a) 2·87 grains of substance gave 6·05 CO_2 2·09 HO.
(b) 3·61 ,, ,, 7·60 CO_2 2·63 HO.
(c) 2·91 ,, ,, 4·10 chloride of silver.
(d) 4·84 ,, ,, 3·97 ,,

	a	b	c	d	Theory.
Carbon,	57·49	57·41			57·98
Hydrogen,	8·09	8·09			7·72
Chlorine,			34·57	34·21	34·30
					100·00

As this substance could not be distilled by itself without decomposition unless in vacuo, I was not able to take its vapour density. It possesses an extremely fine and agreeable smell, and may be kept for any length of time without undergoing any decomposition. When boiled with nitrate of silver, a peculiar detonation takes place, and chloride of silver is formed.

Before leaving the compounds which are produced by the action of hydro-

chloric acid, I must observe that only recently I got another crystalline compound which had been formed by the mere contact of the crude oil with commercial hydrochloric acid, which, however, I have not yet analysed, and must therefore preserve for a following paper.

BROMO COMPOUNDS.

VIII. Tetrabromide of Cajputene, $C_{20} H_{16} + 4 Br$.

When the rectified oil is shaken with bromine water, a red resin is formed, out of which a solid substance crystallizes in small white prisms. This crystalline compound, however, is unmanageable, in consequence of the readiness with which it deliquesces and decomposes. When dry bromine is dropped into the oil a very brisk action takes place, and the sides of the vessel become covered with yellow needles, but which immediately disappear again; if bromine be added so long till almost no reaction is observed in the fluid, a dark, thick, and viscous oil is produced, which, after the lapse of several weeks, deposits a granular substance. As soon as this is observed, alcohol is added to the whole mixture, and boiled along with it. By this operation the granular substance is extracted, and a heavy oil left behind. On the cooling of the alcohol a soft crystalline substance is deposited, of a fatty lustre, resembling very much cholesterine when crystallizing out of the same menstruum. The following are the details of its analyses:—

(a) 2·60 grains of substance gave 2·51 CO_2 0·994 HO.
(b) 3·21 " " 3·05 CO_2 1·20 HO.
(c) 3·27 " " 5·38 bromide of silver.

	a	b		Theory.
Carbon,	26·32	25·97	. . .	26·31
Hydrogen,	4·24	4·15	. . .	3·52
Bromine,	. . .	. . .	70·03 ;	70·17
				100·00

This substance is soluble in ether and boiling alcohol; it melts at 60° C., and solidifies again at 32° C. When submitted to dry distillation, the fluid which passes over crystallizes again in the cooler parts of the retort; whether this product is changed or not I have not yet ascertained. When boiled with a solution of caustic potash, the tetrabromide seems to remain unaltered.

Another crystallized bromine compound has been obtained by the action of phosphorus, dissolved in bisulphide of carbon, on the oil dissolved along with bromine in the same menstruum; the substance, however, at my disposal was so limited in quantity as to preclude the possibility of a satisfactory analysis.

IODINE COMPOUNDS.

XI. Hydriodate of Hydrate of Cajputene, $C_{20}\ H_{16} + HO + HI$.

If iodine be added in small quantities to the crude or rectified oil, no reaction seems to take place; if, however, the fluid be heated, such is observed, as the oil, under the evolution of fumes of hydriodic acid, changes into a black heavy fluid; but in order to get a crystalline compound, no artificial heat in this way is allowed to be applied, as by its application the action of the iodine goes too far, resulting in a viscous substance, out of which nothing can be made. After the addition of the iodine the fluid must be stirred rather constantly, and the heat thus produced by the friction of the rod, as well as the mechanical distribution of the iodine, favour the action between the two substances, so that after a few minutes the temperature of the fluid rises from 10° to 40° C. When this is observed, no more iodine is to be added, and the whole vessel is immersed in cold water, when, after a very short time, a black crystalline compound is deposited in the bottom of it. After the oily fluid is filtered off, the solid substance is pressed between bloating paper, and, when nearly dry, dissolved in alcohol or ether, out of which it crystallizes in prisms of beautiful yellow-green metallic lustre.

The following are the results of some of the analyses performed with it:—

(*a*)	3·63 grains of substance gave	5·71 CO_2	2·30 HO.
(*b*)	3·26 „ „	5·18 CO_2	1·97 HO.
(*c*)	2·69 „ „	4·28 CO_2	1·69 HO.
(*d*)	5·55 „ „	4·78 iodide of silver.	

	a	*b*	*c*	*d*	Theory.
Carbon,	42·91	43·33	43·21	.	43·95
Hydrogen,	7·01	6·71	6·98	.	6·59
Oxygen,	.	.	.	.	2·94
Iodine,	.	.	.	46·51	46·52
					100·00

This compound is very soluble in alcohol and ether, insoluble in water, in contact with which it does not become decomposed. It is, however, a very unstable substance, as it easily deliquesces in the course of time, and when melted, which it does at 80° C., it is not recrystallizable. In contact with a cold solution of potash it soon assumes a fluid condition, losing some of its iodine, which at a raised temperature it gives off entirely.

X. Hydriodate of Cajputene, $C_{20}\ H_{16} + HI$.

A solution of phosphorus in bisulphide of carbon is added to a solution of iodine and oil of Cajeput in the same menstruum. As soon as this is done, a very brisk reaction takes place; the vessel becomes so hot that it cannot be touched by the bare hand of the operator; red oxide of phosphorus is formed

and precipitated; the oily fluid acquires a reddish colour, and gives off fumes which, by the prevalence of the volatile oil, I could not exactly recognise, nor was I, by the peculiarity of the operation, able to receive them under a pneumatic trough. The reaction, however, may be represented by the following simple equation:—

$$3\,(C_{20}\,H_{16}) + 6H + 6O + 3PI =$$
$$3\,(C_{20}\,H_{16} + HI) + H3P + PO + PO5;$$

according to which gaseous phosphoretted hydrogen, oxide of phosphorus, and phosphoric acid would be formed; the last two of which I always found present in the fluid out of which the Hydriodate of Cajputene, in the course of ten or twelve days, crystallized. These crystals are deposited in cells like those of beehives, and possess a black metallic lustre. The following are the detailed results of the analyses:—

(*a*)	4·39 grains of substance gave	7·29 CO_2	2·48 HO.
(*b*)	3·01 „ „	5·01 CO_2	1·72 HO.
(*c*)	5·54 „ „	5·02 iodide of silver.	

	a	*b*	*c*	Theory.
Carbon,	45·29	45·36		45·45
Hydrogen,	6·31	6·35		6·43
Iodine,			48·85 I	48·12
				100·00

Hydriodate of Cajputene is soluble in alcohol and ether, and more stable than the preceding iodo-compound, as it remains for any length of time, and even if boiled with a solution of potash, unchanged.

Secondary products of this and the other iodo-compound I intend to describe in a following paper, which I will endeavour to finish as soon as possible.

Finally, I consider it my duty to express my sincerest thanks to Professor Dr Thomas Anderson, who so generously and forbearingly supported me with all kinds of mental and material aid previous to and during the time of this investigation.

XVI.—*Notes on the Mountain Limestone and Lower Carboniferous Rocks of the Fifeshire Coast from Burntisland to St Andrews.* By the Rev. THOMAS BROWN, Edinburgh.

(Read 17th April 1860.)

Introduction.

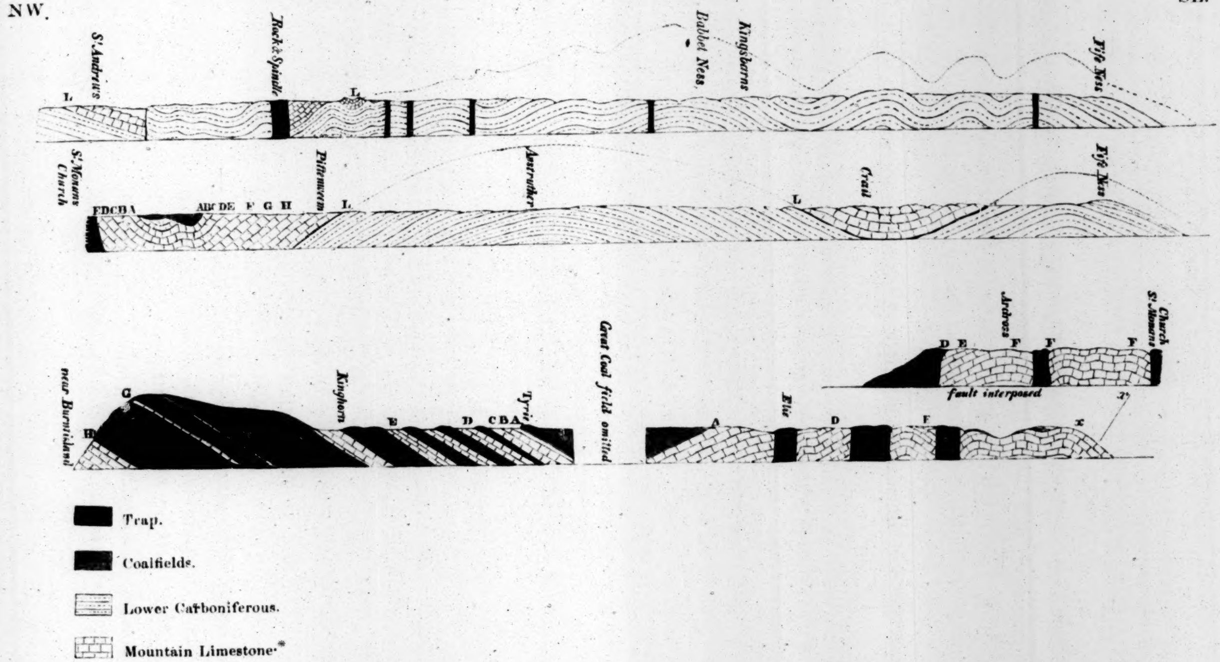
In this paper I shall first refer to the circumstances under which the following observations were made.

I had gone in the autumn of 1856 for a few weeks to Elie on the Fife coast, and was induced, as a means of relaxation and exercise in the open air, to pay some attention to the geology of the neighbourhood, resuming for a brief interval what was once a favourite pursuit. About a mile to the east of the village, I found a stratum well deserving attention—a thin bed of limestone—dipping inland a little beyond the cliff on which stands the ruined Castle of Ardross. The fossil shells which it contained were of unusual form, and beautifully preserved; there were fish remains of two or three species, and a small group of crustaceans still more remarkable. Among the fish I thought I could detect the large scales of an Irish species—the *Holoptychius Portlockii*—and among the crustaceans there were the valves of Dithyrocaris, a genus particularly characteristic of the Irish beds. At once the question arose whether these fossils might not serve as links connecting this Ardross bed with the Irish series. The point was of the more importance, that our leading geologists had been differing widely as to the true position of our Scottish coal strata in the geological scale. The lamented Professor EDWARD FORBES had assigned them a place comparatively high, while Sir RODERICK MURCHISON, with surer judgment, had taken the opposite view and put them beneath the Newcastle coal-field. If any light could be thrown on this question, it might prove of some interest to the Scottish geologist. My first object, then, was to ascertain the level on which the Ardross limestone lay among

our own strata; but this proved at first a question of unexpected difficulty. The coast near Ardross is cut up by trap in the most singular way, and the sedimentary strata are fractured and isolated into patches, in one of which the bed in question is situated. Looking into our local authorities, I found Mr MACLAREN gave no assistance, Dr ANDERSON was silent, and even Mr LANDALE, in his valuable Essay, was still more discouraging. East and west there is no lack of detail in his account of the coast; but precisely here for some distance on either side of Ardross he gives up the case as hopeless, the trap having reduced the whole to "a heap of ruins." A rapid glance at the rocks convinced me that matters were not so bad as this. At all, events the attempt to reduce these beds to order promised to give pleasant occupation for three or four idle weeks. Selecting, accordingly, a fixed point, I began at first, quite mechanically, noting each bed as it came, —its composition, thickness, dip, strike, and gathering such fossils as might serve to identify it—the results being laid down each evening in detailed sections. It ended, indeed, in my making (besides the sections) a ground plan of the coast from Elie to St Monans. And very singular it was to see how, under this treatment, the beds fell into their places, and the supposed heap of ruins became an orderly series. Through faults, convolutions, and outbursts of trap, the strata could be distinctly followed westward into the coal-basin at Earlsferry, and eastward into that of St Monans.

The position of the Ardross bed being thus determined, other questions arose. The limestone strata of Burntisland have long been a fixed point well known to geologists. Where was the level of the Ardross bed as compared with these Burntisland strata, and generally, how would the western side of the basin correspond with what I had found on the east? This led me to examine the shore from Invertiel to Burntisland, and nothing could be clearer than the general resemblance. Beds with which I had made myself familiar came up in regular order. The thick white limestone of St Monans, for example, distinguished for its abundance of Zaphrentes and similar corals, was there in position, covered by the same fossils still larger and more abundant. Going on as far as Burntisland, I found the relative position of the strata to be as shown in the section.

Another question referred to the underlying series of rocks. On the shore to the east of St Monans, I had seen the Ardross bed overlying that great mass of strata which Mr MACLAREN has termed the calciferous sandstones. What was the character and relations of this lower group? This investigation I found one of extreme interest. It led me first as far as Anstruther; then past Crail on to Fife Ness, and then to where the rocks are lost in the sand a little to the north of St Andrews. It has occupied my autumn leisure for several years—in some cases, however, only a few days being at my disposal. I beg to offer to the Society a notice of such facts as I have observed on the following points, viz.:—



* It consists chiefly of shales and sandstone, with a few beds of limestone, but is marked thus in the section to express the opinion (here advocated) that the mass is the equivalent of the Mountain Limestone of England—lower portion. The dotted line marks the supposed level which (if the strata had been continuous) would have been occupied by the bed L.—the base line of the Mountain Limestone.

NOTE.—In order to bring the section within proper limits, it has been divided into two parts, but they should be viewed as continuous. For part of the distance between Elie and St Monans a double line of section is given to represent the rocks on both sides of the fault. The inward termination of the line *x x*, which marks the course of a stratum across the end of the fault, should have pointed more to the west. The remarkable contortions in the cliffs to the east of St Andrews, and those near Newark Castle, should have been more strongly represented than they are in the section.

I. The General Course of the Strata.

The section passes along near high-water mark, the strata being supposed to be cut at right angles so as to show their real thickness only, not the space they occupy on the shore. From Fife Ness to St Andrews they are laid down in reverse, as if the spectator were looking seaward, and this is done to bring the corresponding portions of the two shores into comparison.

From Burntisland to Inverteil the great feature is the immense development of trap beds, amidst which the sedimentary strata lie conformably. The limestones G and H,* with other beds as far as Kinghorn, are estuarine, and then come the six upper marine limestones, all dipping beneath the great coal-fields.

Rising at Elie harbour in reverse order the beds are with some difficulty to be made out covered as they are at some points by sand or obscured by trap, at others as in Woodhaven almost removed by quarrying, and complicated throughout by the thirty-fathom fault, yet with patient attention the position of the whole series can be well enough traced. The fault cuts the Earlsferry coal-field in two, passes along-shore in front of Elie, goes, according to Mr Landale, through the "Taft," may be seen west of Ardross skirting *low-water* mark till it touches the bend of the coast west of Newark, where it seems to vanish.† Outside this line the beds are thrown up and carried (the field geologist well knows how) in the direction of their dip far out of the bearing of the same beds as they lie in-shore. The middle portion of the coast between Elie and St Monans, consisting of the lower beds, is estuarine. Approaching Newark, these strata become remarkably contorted, dipping into little basins, but rising at each movement into higher beds, till the six marine bands of limestone finally fold over and plunge beneath the coal-field at St Monans. Rising again to the east all trap is left behind, and the sequence of the whole beds is singularly clear as they lie exposed along the shore like the mighty pages of nature's book. Passing through the same estuarine beds the strata beyond Pittenweem rise into bold cliffs, remarkable for the depth of the shales which they display, and at that point occurs the limestone L, so important in the classification of the whole series. Eastward among the fine rocks of the Billow Ness lie the thin limestone bands of the lower series, and the shales charged with numerous vegetable remains, continuing down till the anticlinal axis is reached at the harbour of Anstruther. From Anstruther to Crail the same rocks are repeated—the depth of the whole series, however, being apparently greater and—the sandstones especially—more powerfully developed. A red colour

* Owing to the small size of the section, as given in this paper, it has been impossible to represent the separate beds of limestone, or the sub-divisions of the upper group. For the same reason it has been found difficult to give the angle of dip with anything like minute accuracy. Some of the lesser bendings of the strata are omitted—only the general results could be given.

† This point is marked in the section by the letter *x*.

from iron tinges some of the limestones, and especially the bed L, which at Pittenweem is dark gray. At Roome beyond Crail the synclinal axis is reached: the beds again show a descending series till they fold over an anticlinal close to Fife Ness. That point forms a splendid display of powerful yellow sandstone, dipping with gentle slope towards the ocean whose stormy waves it has flung back for ages.

Away to the north, and on as far as St Andrews, my examination of the coast was more rapid. In the section as it approaches Crail, and goes north of Fife Ness, I do not attempt to show the effect of the faults, but the general features of the strata will be found given with sufficient accuracy. Passing Balcomie, the lower series of rocks is well displayed; but especially from Cambo Point, on beyond Kingsbarns and down to the lowest beds at Babbet Ness, all is singularly complete and clear. At the latter point, the lowest strata of the whole coast from Burntisland to St Andrews are reached, lying considerably beneath the level of Anstruther. Passing Pitmilly Burn, the section exhibits the various bendings of these strata, till the limestone L is found on the shore near the Rock and Spindle. On to St Andrews the foldings seen in the cliffs form a striking feature of the coast, till at the Witch Lake, with its deep shale beds, the limestone L again comes into view.

The general aspect of the coast thus described will best be understood by a glance at the accompanying section. Omitting the minor foldings of the strata there are, east of the Ochills and on to Fife Ness, four great anticlinals, with their accompanying basins on either shore. The first of these basins on the coast of the Firth (not shown in this section) reaches from Alloa and Dunfermline to Aberdour. It corresponds to that on the east, in which St Andrews is situated, and whose southern margin touches the Babbet Ness. The second stretches from Aberdour to a point beyond Elie, where the axis, though obscure, is really present; and so on to Fife Ness, every anticlinal and basin on the west has its corresponding feature on the east, though not always in the same relative proportions. One marked difference, however, will be observed. Along the German Ocean the beds have been lifted to a far higher level, as is shown by the dotted line which represents the supposed level of the bed L. High above the ground on the eastern side, it is often from one to two thousand feet beneath it on the shores of the Firth.

II. The Trap Rocks.

These I did not attempt to study, but one or two points may be mentioned which came under my notice.

First, A large portion of these traps can have had nothing to do with the elevation of the other strata. On the one hand, they are so interstratified that on looking to the details one can hardly resist the inference that they were contemporaneously formed; and on the other, they have themselves been acted on much

as the other rocks by the forces of elevation. A glance at the section from Pettycur to Inverteil will show how the beds of trap and the other strata have been lifted together to the same angle of dip. Another example is still more instructive. Not far from Queensferry there is, to the east of St David's, a mass of tufaceous trap, and south of St Andrews there is a mass of sedimentary strata both contorted in a similar way. They lie in the same position on the southern rise of the great basin—which leans against the axis of Aberdour on the one shore, and Babbet Ness on the other. The force which caused these convolutions must thus have acted over a wide stretch of country, and the traps and the sedimentary strata must have yielded alike to its power.

Second, There are trap rocks evidently intrusive, and of subsequent formation, containing as they do fragments of the other strata. Every Edinburgh geologist knows well the Basalts, Tufas, and Amygdaloids of the coast from Pettycur to Inverteil. In the Huttonian and Wernerian controversy this western series was the stronghold of the Wernerians. It seems strange that their adversaries did not claim the Elie side, where the intrusive traps may be studied to singular advantage.* Perhaps the most common appearance resembles that at Edinburgh Castle—the sedimentary strata at the point of contact being fractured and bent downwards; but there is this difference, that the phenomena can be studied not in section, as at the Castle, but amid the bared rocks of the coast they are laid open as on a ground plan.

Whether these intrusive traps had anything to do with the elevation of the other strata seems extremely doubtful. For the most part they appear to penetrate the mass much as a musket bullet does a pane of glass, fracturing the portions in immediate contact, but leaving the general plane of the beds unchanged. A single example near Kinghorn is the only instance of what seems elevation resulting from the intrusion of trap. That some deep-seated force of elevation has acted over the district is indeed obvious. Starting at Fife Ness, we can trace the long, rolling undulations of the strata, as if lifted over the crests and sinking into the troughs of some gigantic sea. How vast the elevation must have been at first, and how immense the denuding agencies by which all was subsequently planed down to its present level, may be seen from the dotted line showing the supposed level of the bed L, itself very far below the coal-fields. I have seen, however, no

* It is not intended in this or the following statements to advance any theory as to the formation of these rocks, the term intrusive being merely used to indicate that the previously formed sedimentary strata must have been consolidated and fractured before these traps could have come into their present position. While on the west the two kinds of rock lie for the most part conformably interstratified, it seemed deserving of notice that on the east side of the basin, when they come into contact, there are in most cases clear traces of convulsion. A geologist holding extreme Huttonian or extreme Wernerian opinions might easily enough find on these shores not a few facts in support of his favourite views on either side, but there are still considerable difficulties in the way of any theory which shall explain and harmonise *all* the phenomena.

clear evidence to connect these intrusive traps with the deep-seated forces which produced such vast results. The question would require much closer attention than it was in my power to give; but everything seemed to support the views so ably propounded by Professor ROGERS in the Transactions of this Society.

Before entering on the sedimentary strata, it is right to state that the object of this paper is restricted properly to a single point. The petralogy of these coasts —the mineral structure of their rock-masses—I do not refer to, except incidentally. For the present, my remarks are confined to one point, a consideration of the fossils in connection with the different levels at which they occur, and the light which is thus cast on the different groups of strata in their geological relations.

III. MOUNTAIN LIMESTONE.

In regard to the classification of the rocks of this district, I have been led to deviate to a considerable extent from the views commonly held. If about 1400 feet be taken from the lower series—the calciferous sandstones of Mr MACLAREN—and added to that upper marine zone, usually termed the Mountain Limestone, then a well-defined base line is obtained for the upper division, and the two groups may be distinguished by satisfactory characters. To the whole of the upper division, I would extend the term Mountain Limestone; and to the underlying group the term Lower Carboniferous. The reasons for this arrangement I shall afterwards state. Assuming it in the meantime, the Mountain Limestone will present the three following portions, viz.:—

1. *The Six Upper* Limestones*, A *to* F.

Immediately underlying the coal-fields on the Fife coast, we find these beds with shales and sandstones intercalated. The whole body of strata is set down by Mr GEIKIE as from 150 to 200 feet thick in the Lothians; and by Mr PAGE as 200 feet thick in Fife. If the lowest bed F be included, I am disposed to put the estimate considerably higher. The Ardross limestone, to which I referred at the outset of this paper, is the bed F, the lowest of these six beds.

It is the abundance of their fossils which render these six limestones so important. As it is often difficult to know how far such lists as the following may be depended on, I may mention that all the fossils here named were collected by myself, the beds and the localities being carefully noted. With the exception of one or two of the commoner species, they will all be submitted along with this paper. The determination of fossil species is often a point of much difficulty, especially where no collection exists to which reference can be made; and I may therefore mention, that the lamented Dr FLEMING and Dr SCOULER of Glasgow, two of our highest authorities, did me the favour to examine part of my collec-

* The term *upper* is used only relatively. They form the highest portion of the strata to which this paper refers, underlying the coal-fields.

tion, and that I have submitted the whole to Mr SALTER, Palæontologist to the Government Survey, whose assistance has been of special importance, not only from his great eminence in that science, but from his familiarity with the fossils of England and Ireland. The system of nomenclature in his hands being uniform, we can employ the species here named with confidence as points of comparison with distant formations. A considerable proportion of the following list are new to Scotland. Two or three of the names are given on the authority of Dr FLEMING; the rest on that of Mr SALTER.

Fossils.

Corals.—The following seem the most common species:—

Chaetetes tumidus.
Aulophyllum fungites.
Lithostrotion junceum.
L. fasciculata.
Zaphrentis species.

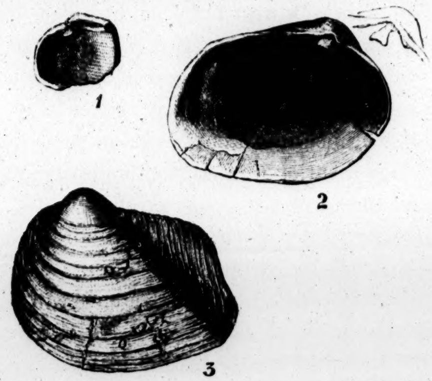
To these may be added (from the Bryozoa), the *Fenestella plebeia*, which is plentiful in all the strata.

Shells.—From the bed F at Ardross, I obtained the following, viz.:—

1. Lingula mytiloides.
2. Productus semi-reticulatus.
3. Pecten Sowerbii.
4. Edmondia unioniformis.
5. Schizodus sulcatus.
6. Nucula gibbosa.
7. Nucula attenuata.
8. Macrocheilus ovalis.
9. Bellerophon Urii.
10. Bellerophon decussatus.
11. Nautilus subsulcatus.
12. Orthoceras cylindraceus.

Along with these there were other species belonging to the following genera not yet determined, *Orthoceras*, *Schizodus*, *Arca*, *Modiola*, *Loxonema* and *Goniotites*. Of the whole perhaps the shells most characteristic of the bed are a strong handsome *Schizodus*, and a thin stiletto-like *Orthoceras*, whose long, taper form does not seem as yet to have been figured or described.

Fig. 1.



1. Right Valve. 2. Left Valve. 3. Outside of Left Valve.

Of the *Schizodus*, figures are here given from characteristic drawings furnished by Mr SALTER.

Dr FLEMING, to whom I formerly submitted this shell, considered it to be the *Anatina attenuata* of M'COY, but held that it had been erroneously referred to that genus. He possessed numerous specimens from a bed near Colinton, where it occurs in such abundance as to suggest the idea of its having been gregarious; but the specimens from Fife were in better preservation, and he intended to have them laid open and submit them to a careful examination, in order to determine the generic character. Circumstances prevented this, but it has now been made clear by Mr SALTER. The species seems to have belonged properly to the Lower Carboniferous group, rather than to the Mountain Limestone. It is common enough, indeed, in the bed F, to be characteristic of the stratum; but when met with in the lower rocks, it shows itself in a far different way, and in far greater abundance. This is seen not only at Colinton, but in a very remarkable bed south-east of Kingsbarns, where, in countless masses, it covers the surface of the rock in a state of preservation singularly fresh and beautiful. On passing up into the Mountain Limestone it occurs rather in a straggling condition, and in comparatively scanty numbers.

Passing to the five overlying beds, besides most of the shells just enumerated, we find the following:—

1. Athyris ambigua.
2. Athyris Royssii.
3. Chonetes Hardrensis.
4. Chonetes variolata.
5. Discina nitida.
6. Leptaena crenistria.
7. Productus giganteus.
8. Productus punctatus.
9. Orthis Michelini.
10. Orthis filiaria.
11. Orthis resupinata.
12. Athyris gibera.
13. Productus longispina.
14. Rhynconella pleurodon.
15. Spirifer duplicicosta.
16. Spirifer trigonalis.
17. Avicula rugosa.
18. Aviculopecten interstrialis.
19. Mytilus triangularis.
20. Nucula tumida.
21. Euomphalus carbonarius.
22. Orthoceras annulare.

Along with these there occur species of *Schizodus*, *Aviculopecten*, *Modiola*, and *Turbo*, not determined. There is also one species of *Sanguinolites*, which Mr SALTER pronounces to be new.

Crustaceans.—The bed B east of St Monan's has yielded various specimens of a species of trilobite—the *Griffithides mucronatus;* and in the bed E, near Kinghorn, I found a plate of the *Eurypterus Hibberti.*

It is the bed F at Ardross, however, which has proved most productive of these remains. They are of two kinds. *First,* Those belonging to the genus Dithyrocaris, chiefly detached valves; one specimen, however, showing distinctly the tail spines, and another the jaws. Mr SALTER, whose authority stands so high in regard to this class of fossils, has decided that the specimens belong to two species both hitherto undescribed.

The other crustaceans are of a form nearly allied to the shrimp, and closely resemble the species of Gampsonyx, described by VON MEYER, from the coal for-

mation of Saarbruck in Lorraine. The shelly covering seems to have been peculiarly thin and tender, for though the limestone is singularly favourable for their preservation, yet there is a difficulty in making out the form with sufficient distinctness for scientific description. Its resemblance to the shrimps of our shores is obvious, however, at a glance, and like them it seems to have been social in its habits; for at the only spot in which it occurred a whole swarm was laid open at once, and very remarkable it was to see these tiny forms of crustacean life lying close to each other in every imaginable attitude on the surface of the rock. For the following remarks and figure, singularly true to nature, I am indebted to Mr SALTER:—

Fig. 2.

Uronectes (Gampsonyx of Jordan) socialis, n. sp.

"There can be little doubt this is of the same genus as the curious *Gampsonyx fimbriatus* of Jordan, figured so well by VON MEYER in his "Palæontographica" for 1854, Vol. VI. t. t. That species was found in the coal of Saarbruck and Salzbach, and it was regarded by VON MEYER as belonging to the Amphipod group, the only example yet known of a true Malacostracous crustacean below the New Red Sandstone. Our specimens, though crushed, show much fewer segments than the German fossil, and it is no doubt desirable to compare specimens of both. I am not clear about any appendages to the head, which appears (if that be not due to pressure) to be elongated. Seven body-rings and a minute telson are all that can be made out. But the tail appendages are very like those of a shrimp, and the body-rings not dissimilar."*

A single remark of a general kind I may be permitted to offer. One of the most delightful passages in PALEY'S "Natural Theology" is his description of the shrimp, and the proof of the goodness of God in communicating such manifest enjoyment of life to these lower orders of being, diffusing such happiness among myriads of His creatures. When we look back into the old creations of geology with their predaceous races, covered with bony armature, and furnished with instruments of destruction so formidable, we are ready to feel as if the world must have been a scene only of darkness and terror; yet the light of God's love must have shone then as now, and perhaps the little crustacean here before us may give some indication of this truth. If PALEY can stand on our modern shores, and, amidst the social instincts of its shrimps, can point to the fulness of their enjoyment as a proof of the goodness of God, I know not why, in the little Gampsonyx of these primeval rocks, evidently not less social in its instincts, we may not read the same lesson, and feel that then of old, as now, the world which He had made bore witness that "God is love."

Fish.—These remains deserve particular attention. At Ardross I detected small

* Mr SALTER, MSS.

scales of some species of Palæoniscus, and one good specimen of an Amblypterus, which seems to be the *A. striatus.* There were teeth and scales also of a Holoptychius; some of the latter more than an inch in diameter, and their resemblance to the figures of the *H. Portlockii,* published in the Report of the Irish Survey, seemed to be complete. If the fish remains at Ardross are thus not devoid of interest, those on the west side of the basin near Kinghorn are still more important. It was in connection with these that I obtained one of the most striking proofs of the identity of the corresponding beds on the two sides of the basin. Beginning at Inverteil, or rather at Tyrie, I had traced the strata backwards and downwards through every link of the series, to that level on which the fish occur on the east. The limestone bed was there, its corals and shells agreed, but at first there seemed no trace of fish. The point was important, the opportunity for search was good, for the beds lay open, intercalated between two sheets of trap. Beginning at the top, and resolved that nothing should escape, I had nearly gone over the whole, when, about three inches above the lowest trap, I caught the glitter of a ganoid scale, and laying open the spot, a very slight effort disclosed a whole array of fish remains—spines, plates, teeth, scales, &c., in singular abundance. I was reminded of the famous bone-bed at Ludlow, described as resembling a mass of broken beetles. This was obviously a similar formation of the carboniferous system. About an inch in thickness, imbedded among shale with a few shells, and charged with its abundant fish remains, all disjointed, but in beautiful preservation, I could trace it, running at its own level for fifty yards, till lost at low-water mark in its course seawards. All the fish I had found at Ardross were there, with additional species; but there was one new and most noticeable feature, the abundance of Cestraciont teeth—the crushing teeth of ancient sharks. Would it not be possible to find these fossils also on the eastern side of the basin? Returning to Ardross, I sought for them in the bed F, but in vain. In the bed E, I also failed in finding them; but at last the limestone D, and especially a bed of underlying shale, yielded a considerable number of specimens. The links of connection between these beds, separated at a distance of some twenty miles, were thus made clear, and it was also established that fish remains were diffused through the lower half of these six marine limestones.

The disjointed state of the remains from the fish-bed renders it difficult to identify the species. There are head-plates and scales of *Rhizodus Hibberti.* There is a well-preserved jaw undetermined, and scales of Amblypterus. Besides these there is a spine of Ctenacanthus, which Sir P. EGERTON considers as hitherto undescribed, and among the teeth there are several fine specimens belonging to the genus Cochliodus, also marked by him as new to science.* More than by all these, however, my attention was attracted by some plates belonging to the great

* It was through the kindness of Sir R. MURCHISON that the specimens were submitted to Sir P. EGERTON, our highest authority in fossil Ichthyology.

class of tuberculated fish. I extremely regret that from the softness of the shale it has been impossible to preserve them in anything like their original completeness. When first laid open they seemed unequivocal plates of some species of Pterichthys. When submitted in their present state to Sir P. EGERTON he has marked them as "very doubtful—probably not Pterichthys." Enough, however, still remains to show that they must have belonged to the great class of tuberculated fish. At Mr SALTER's request, I have agreed to place these specimens in the new museum here. Should they prove to have belonged to any genus allied to Pterichthys, the discovery would be one of considerable importance. The range of that great family would no longer be confined to the Devonian formation, and this point might have an important bearing on questions connected with systematic geology. Already, in England and elsewhere, these tuberculated fish have been found up to the highest beds of the Devonian system; but should their discovery at Kinghorn be confirmed, they must be held to have existed through the long period of the Lower Carboniferous group, and to have passed far up into the Mountain Limestone. It would be well, meantime, if the attention of our local geologists were directed to this bone-bed. A thorough search by those who could command the necessary time would yield results of considerable interest. Before leaving these fish remains, it is right to call attention to their position as belonging to the six upper marine limestones. In the corresponding marine formation of Yorkshire, the fish remains are few or none; and in the same marine band, as found in the Lothians, Mr GEIKIE mentions that fish remains are also absent. It will be remembered that the ganoid fish now living are found only in fresh water, and it might have been argued that their ancient congeners were also fresh-water fish. This idea might have found support from the absence of their remains from the deep marine formation of Yorkshire, and the marine beds of the Mountain Limestone in the Lothians. The Fife beds, however, at once place the whole matter in another light. At Ardross we have the remains of Rhizodus and Amblypterus intermingled with the Cephalopods and Brachiopods of the ancient seas. At Kinghorn the bone-bed gives us the remains of the whole family of carboniferous Ganoids, side by side with those of Cestraciont Sharks, and Brachiopods like the Lingula, all evidently marine.

One other fossil deserves notice—the *Serpulites carbonarius*, which is confined, so far as I observed, to the two lower beds E and F. Immediately to the west of Newark Castle, the bed F yields these remains in great abundance, and fine condition, in many cases filled with carbonate of lime.

2. *The Estuarine Strata between F and L.*

Underneath the six limestones we find a series of rocks of considerable depth, apparently 1400* feet. That they are fresh water or estuarine, is shown by the

* Since presenting this paper to the Society, I have gone over these beds to the east of St Monans

sudden disappearance of the crinoids, corals, and other marine fossils so abundant in the overlying beds. The *Cypris scoto-burdigalensis* is also found in layers so distinct, and entering so largely into the composition of the rocks, as fairly to indicate fresh water conditions. One marking feature also is the abundance of *Sphenopteris affinis*, unknown in the overlying limestones, but all along between Elie and St Monans, and farther east down as far as the bed L, it is the prevailing fossil in this the Estuarine part of the series.

The well-known Limestones of Burntisland, with their numerous fish remains, lie on this level. It is, however, to the east of St Monans and on beyond Pittenween that the series can be studied to best advantage. The very point in the descending order can be fixed where the Sphenopteris begins, and its rapid increase traced downwards through the strata. Two singular beds of limestone, obviously on the same level with those marked G and H at Pettycur, on the west, well deserve attention. They are yellow or pale-buff in colour, distinctly brecciated, often siliceous and cherty, and so much harder in structure than the sandstone, that they may be traced on the shore west of Pittenweem harbour, standing boldly up in marked outline and running seawards like tall slanting walls. In colour and structure they are quite different from the six overlying limestones. On the west side there is a bed at Pettycur marked G, which may be traced running inland through the railway cutting and sweeping round till it reappears behind the Binn, which shows at certain points much of the same colour and some tendency to the same brecciated structure, but from the absence of siliceous matter it is comparatively soft.

West of Newark there is in the coal-shale a bed with nodules of clay ironstone, containing coprolites, from which I extracted two complete specimens of fish—a species of Palæoniscus. Near the same point, close to an out-burst of intrusive trap, is a layer containing good specimens of carboniferous wood in a state of charcoal, some of the fragments being very distinct.

To this part of the series also belongs a shale-bed beyond Crail (close to the farm-servants' houses at Kilminning) containing fish remains, among which I could detect the scales of Megalichthys and Eurynotus. It was there I obtained the jaw of a small species of fish belonging to the family of Pycnodonts, with five rows of tesselated teeth. Of this family, so common in the secondary strata, only one previous example is mentioned by Professor OWEN as having been found in the palæozoic rocks, a small jaw described as occurring in the coal-field at Leeds. That found at Kilminning was upwards of 1000 feet below our Scottish coal-fields, and is probably therefore of a still older date.

in order to ascertain the thickness of the mass of strata measured in a line perpendicular to the plane of the beds. Taking the direct distance from F to L at right angles to the general strike, and taking the average dip from a series of measurements, the result is that this mass of estuarine beds is about 1400 feet in thickness. Such measurements are of course only approximate.

3. *Limestone L. Line of lower Encrinites.*

Underlying these estuarine beds we have already referred to a thin stratum of marine limestone, seen in the cliffs of Pittenween. At various points along the coast it again occurs as shown in the section. Its fossils are numerous, and obviously, even at first sight, similar to those of beds A to F. The following kinds have been noticed :—

Crinoids.—In speaking of the upper limestones, I should have remarked that these fossils (the Crinoids) are found everywhere in great profusion in the form of detached vertebræ or fragments of stems. The bed E, west of Ardross, seems to have been a singular storehouse of these remains. Washed out by the sea, they used to lie scattered in thousands along the shore, and under the local name of Croupies were familiar as playthings to all the children of Elie. The deposit seems now to be in a great measure exhausted, and those formerly washed out are buried by the sand.

The Crinoids of this lower bed L are smaller and apparently of different species. There is among my specimens one Rhodocrinus and one Poteriocrinus, the latter showing the head, and being therefore of considerable interest. It has often been matter of surprise why the remains of Encrinites in our limestones should consist entirely of disjointed stems. "What can have become of the *heads* of all our Scottish Encrinites?" a leading naturalist once asked me, adding, that of the thousands of specimens he had seen he could find nothing but the vertebræ. The bold conjecture has, I believe, sometimes been hazarded, that our Scottish Encrinites either never had heads at all or had them of some softer substance than their English brethren, so as not to admit of preservation. This somewhat whimsical idea might perhaps have been met by asking in reply whether there were any analogy to support it; whether other Scottish productions were usually more destitute of head or more soft-headed than those of the south? But there is really no need for pushing the argument. Specimens enough will be forthcoming. Among those here produced is the small head of a Poteriocrinus taken from the bed L, the base of the Mountain Limestone, a little to the south of the Rock and Spindle.

Corals.—Of these I observed four species, two of which are undetermined. The *Chœtetes tumidus* is common, and still more so the *Fenestella plebeia.*

Shells.—Of species not observed in the upper limestones I found the following, viz. :—

1. Spirifer octoplicatus.
2. Aviculopecten arenosa.
3. Sanguinolites tricostatus.
4. Chemnitzia gracilis.

Of species already found in the beds above, there were

1. Productus semi-reticulatus.
2. Edmondia unioniformis.
3. Nucula attenuata.
4. Nucula gibbosa.
5. Bellerophon decussatus.
6. Bellerophon Urii.

Of these, the most characteristic shell at Pittenweem is the Productus; and at Crail, the Edmondia and the Bellerophons, which are abundant and large.

These three portions—the upper limestones, the estuarine beds, and the line of lower Encrinites—have now been described, and their fossils, when viewed together, form an assemblage which all will at once recognise as belonging to the Mountain Limestone. To this point I shall afterwards advert. Meantime, no one can go over the ground without feeling how singularly rich these deposits are in the remains of ancient life. Justice has perhaps hardly been done as yet in this respect to our Scottish rocks. Among the Crustaceans and fish we have seen that there are not a few additions to be made to our extinct Fauna. Of the forty named species of shells recorded in this paper, only twelve are found in Professor NICOL'S list of Scottish fossils, and the specimens I have mentioned as unnamed species will probably furnish still farther additions. It should be remembered that I made no special effort to collect fossils, visited no quarries, asked no assistance, took only what came in my way. The naturalist, who should, with time at his disposal, take up this work would find his researches richly rewarded.

IV.—LOWER CARBONIFEROUS.

Along these shores there occurs a great body of strata underlying L, the line of lower Encrinites.

A distinguishing feature, which at once strikes the observer, is the great prevalence of shell-beds—limestones composed of a single species of bi-valve resembling Unio, and now placed in the genus Myalina or Anthracosia. It were much to be desired that these obscure families were dealt with by some competent naturalist, and their distinctions satisfactorily made out. Meantime, we must be content to refer to them as undetermined species of Myalina. One circumstance connected with these beds is, that they increase as we go eastwards, both in number and size. Thus, taking the axis at Anstruther, I found not more than two shell-beds to the west, only one of which is of importance, viz., that lying among the strata in front of the town. To the east of the axis there are up to bed L at least three shell-bands. The lowest sweeps round from Anstruther, running inland at Kilrenny, where it is comparatively thick. Two others were detected lying at distant intervals in the series above. Near Fife Ness these shell-bands are more fully developed, but it is towards Kingsbarns that they come out in all their force as limestones, four or five feet thick, consisting of consolidated shells piled above each other in countless myriads. They have been compared to banks of mussels, and held to indicate a shallow sea, if not estuarine conditions. There is a difficulty, however, in their extent, reaching from St Andrews far beyond Dunbar, and from Anstruther to Kingsbarns, getting ever the more fully developed. It is to be observed also that those portions of the shore, where there are on other grounds the greatest indications of estuarine conditions (as from An-

struther to Pittenweem), are exactly those in which the shell-beds are least prevalent. One is struck further also with the immense extent to which the ocean of that early time must have been pervaded by this form of life, its waters swarming with myriads of these bi-valves. It can hardly have been a shallow sea, across the bottom of which there stretched continuously layers of dead shells four or five feet in thickness, more especially when we observe that just in proportion as the accompanying beds abound in evidences of marine conditions, these bands of Myalina are the more fully developed.

Among these lower rocks may be noticed the occurrence near Caiplie of what is termed in the neighbourhood the petrified forest, a thick bed of sandstone with twelve or fifteen trunks of trees, some of them prostrate, but most showing their stumps projecting through the rock. As the bed dips at about fifteen degrees to the east, and the trees lie slanting at about seventy-five degrees west, they are nearly perpendicular to the plane of the bed, showing that they must have been growing on the spot when enveloped in the sand. Unlike those of Craigleith there is no real petrifaction; they are simply casts of the inside of the stem from which the bark has subsequently fallen away, but which show obscurely the flutings and other marks peculiar to the genus Sigillaria.

Another circumstance of great importance to the understanding of this lower series is, that at various levels it shows beds with unequivocal marine fossils. Thus there is a stratum with many specimens of Natica in the Billow Ness, and across near Caiplie it is again found with the same pretty little shell still better preserved. Again, in the axis of the anti-clinal, near Fife Ness, there occur, along with some fish remains, species of Orthoceras, Chemnitzia, and Natica, the two last very beautifully preserved. South-east of Cambo is a bed charged with shells, distinctly marine, and on the other side what appears to be the same stratum, more fully developed. A species of Schizodus especially, as formerly stated, is found in great profusion. In the neighbourhood of Caiplie also there is a shale-bed with specimens of Lingula, on a different level from that in which the Natica prevails.

Shells.—Two species may be mentioned, both carboniferous, but different from those already referred to:

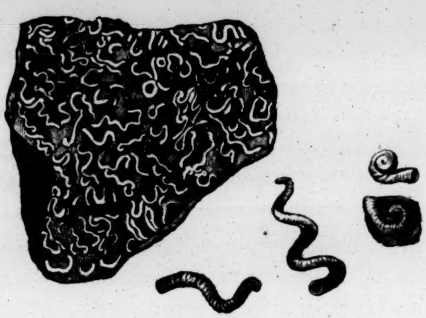
Murchisonia trilineata, from near Cambo.
Lingula marginata, near Caiplie.

Along with these occurred *Orthoceras cylindraceus*, and *Aviculopecten arenosa*. These all comparatively lie deep in the series.

One of the most interesting discoveries which I met with in this lower series is a thin stratum of reddish limestone, charged in great abundance with a little Annelid, a species of Spirorbis or Serpula. It is allied to the *Spirorbis* (*Microconchus*) *carbonarius*, but larger in size, and, instead of being folded on itself like the coil of an Ammonite, is remarkably twisted in a serpentine form.

A clear idea of it will be obtained from the following figures and specific character, with remarks, for which I am indebted to Mr SALTER :—

Fig. 3.



"*Spirorbis* (*Serpula*) *helicteres*, n. sp."

"S. ¼ uncialis, laxe spiratus; anfractibus, 4—5; quorum, 2—3 compactis, reliquis longe vagis,—omnibus compressis. Superficies rugosa, lineis incrementi rugisque irregularibus aspera, nec striata. Apertura ovata, margini haud incrassato."

"This striking fossil occurs in distinct beds, grouped hundreds together, yet without ostensible attachment to any other object than its own species. The helix formed by the compressed whorls is a very open one, and often drawn out to more than a quarter of an inch long; the first whorl or two only being discoid. The surface is roughened by lines and ridges of growth, but has no distinct striæ either longitudinal or transverse.

"*S. Archimedis* of DE KONINCK (animaux foss de Belge PC. G. f. 6), a fossil from the Carboniferous Limestone of Visè, is only slightly compressed. It is much more closely coiled, the whorls touching each other, and has close set striæ and larger plaits in the direction of the lines of growth."*

Another feature to be noticed is the marked abundance of Cyclopteris. This is especially seen among the rocks from Pittenweem eastward. Both plants occur in both portions of the series, but above the bed L Sphenopteris is the prevailing form; below L it is Cyclopteris.

V. RESULTS.—THE TWO GROUPS.

Mr MACLAREN's classification, in his able work on the "Geology of Fife and the Lothians," has been in substance adhered to by subsequent writers. Underlying the coal-field there is first a zone of encrinal limestone, comparatively thin.

* Mr SALTER, MSS. Our fossil is imbedded in the stone, which is to a large extent made up of it; but the weathered surface often shows the fossil very beautifully, the white snake-like form charged with carbonate of lime being well relieved by the dark red of the limestone. The bed occurs among the rocks of the shore near Fife Ness, a short way to the north-west of Balcomie Sands.

Beneath this there is a large mass of strata, the calciferous sandstones of his nomenclature,—the lower carboniferous of subsequent authors. When I began these observations on the Fifeshire coast, I held to this received view, and put the strata into two groups. Down to the bed F all was marine, and marked by me as the Mountain Limestone; below F came the estuarine beds,—the lower carboniferous.

What first shook my confidence in this classification was the discovery of the marine bed L, or rather the results obtained, after a full examination of its fossils. Lying 1400 feet down among these estuarine strata, it exhibited not only the same fauna with the upper six limestones, but that fauna amply developed. Why should it not go into the same group with these upper beds?

Next came the question, whether the difference of character between Estuarine and Marine could form a safe ground for distinguishing the groups,—it might or it might not be convenient as a local arrangement, but if the groups were so formed, would the classification be of any value on a wider area when brought into comparison with the strata of other districts?

But what proved most decisive, was an examination of the great mass of strata underlying L. Studying these lower beds on to Fife Ness and northwards, it became evident that they had a character of their own by which they might be defined and recognised,—that L was really the lowest point or base line of an upper group, and that the two were separated by characters more to be depended on than the difference between a fresh-water and marine formation.

The only difficulty in assigning the bed L to the upper group is the fact that the mass of strata intercalated between F and L are Estuarine, while these two beds are Marine, but there should really be no hesitation in setting aside this character as a ground of distinction. Every epoch has its fresh-water and salt-water beds contemporaneously formed. Just as at this moment deposits are going on simultaneously in our fresh-water lakes like Loch Lomond, in our estuaries, as among the upper reaches of our Firth, as well as in the open sea, all representing the same point of time, so the fact that a mass of strata is estuarine does not in the least disconnect it with the *period* of the two limestone bands between which it is intercalated. It must be grouped along with them, so that the whole mass of the nine limestone bands from A to L, with their accompanying strata, must be associated together.

Now there cannot be any ground even for hesitation as to what portion of the geological scale this group belongs to. The fossils which we have enumerated not only as a whole, must be referred to the Mountain Limestone, but contain a large proportion of the species held to be decisive as characterising that formation. Take a list of shells like *Productus giganteus*, *P. semi-recticulatus*, *P. longispinus*, *Athyris ambigua*, *A. Royssii*, *Rhynconella pleurodon*, *Edmondia unioniformis*, *Bellerophon Urii*, *B. decussatus*,—let these and others similar not only be found, but

be the prevailing forms in a group of rocks, and any one accustomed to deal with such questions will hold the conclusion irresistible—*that* group is simply the Mountain Limestone. This is one of the best marked and most thoroughly understood portions in the whole series of ancient rocks. Powerfully developed in Yorkshire, it passes south by Bristol into Devonshire and Wales, crosses over into Ireland, where, north and south, the level of the great Scaur Limestone has been well recognised. Spreading over the kingdom, this belt of Mountain Limestone lies everywhere on the same geological horizon, and what we have here on the Fifeshire coast overlying the bed L is simply a powerful mass of strata forming a prolongation of the same great series. The limit of the group upwards I have not examined.

The question, therefore, which suggested itself on the shore at Ardross, on first looking at the limestone bed with its fossils, has been satisfactorily solved. Its place is somewhere about 1400 feet above the base of that great series which is recognised over the kingdom as the Mountain Limestone proper.

And now, in regard to the inferior group—the Lower Carboniferous—Mr Geikie recognising the insufficiency of the difference between the fresh-water and marine character of beds as a ground of distinction between the groups, has proposed to regard the whole carboniferous series beneath our coal-fields as the representative merely of the marine Mountain Limestone of Yorkshire.* There seems, however, reason to believe that the lower portion belongs to that antecedent period which ushered in the Mountain Limestone proper. Should this be confirmed, it will give special importance to our Scottish rocks, as casting valuable light on the obscure introductory stage of the carboniferous era. The difference of this group from the other is no doubt only one of degree, for both are carboniferous and belong to the same formation; but referring back to the details of our general description in the preceding section, the following points may be noted as distinctive of the lower series, viz.:—

1. The prevalence of Myalina beds throughout the strata below L.

2. The comparative abundance of *Sphenopteris affinis* above L, and of Cyclopteris below it. Both plants occur in both series, but their comparative abundance is markedly different.

3. The most important point is that the carboniferous fauna of the Mountain Limestone is seen only in an incipient state.

This was not for want of sea-room in which to show itself. There was room for Pectens, Modiolæ, and Schizodi, just as in the limestones above and what is not less conclusive, there was room for Gasteropods like Murchisonia, Chemnitzia, Natica, and Cephalopods, like Orthoceras. But where are the Corals, the Encrinites, the immense development of Brachiopods, all those great characteristic forms of life that make the Mountain Limestone fauna what it is. If they occur

* See his interesting work "The Story of a Boulder," p. 195.

at all it must be scantily, and we seem warranted in holding that the rocks below L exhibit that great fauna only in its feeble beginnings. Thus the bed L, marking the point where it fairly took possession of the ancient seas, forms the true base-line of the upper group.

It may confirm these views to observe that an underlying series of strata of the same kind has been found in other parts of the kingdom. In Yorkshire nothing carboniferous is seen below the Mountain Limestone, but these lower beds have been traced at Bristol, in South Wales, and still more fully in Ireland. The Calp. series in the north and the Comhoola grits in the south, with their accompanying strata, are described as occurring in a position beneath the Mountain Limestone, closely analogous to that of our lower series. In these different districts the group, while agreeing in its general features, varies according to the locality. These varying aspects should be carefully studied and compared, and when the results are fully wrought out, the effect will be to unfold many a deeply interesting page in the opening history of the great carboniferous era. It is from Fife Ness on to St Andrews that the beds are most fully developed with us, and the few details which I have endeavoured to record, will, I trust, be sufficient to show the interesting nature of the field, and the value of those results which are yet to be brought to light.

XVII.—*On the Reduction of Observations of Underground Temperature; with Application to Professor Forbes' Edinburgh Observations, and the continued Calton Hill Series.* By Professor WILLIAM THOMSON.

(Read 30th April 1860.)

I.—*Analysis of Periodic Variations.*

1. Every purely periodical function is, as is well known, expressible by means of a series of constant coefficients multiplying sines and cosines of the independent variable with a constant factor and its multiples. This important truth was arrived at by an admirable piece of mathematical analysis, called for by DANIEL BERNOUILLI, partially given by LA GRANGE, and perfected by FOURIER.

2. To simplify my references to the mathematical propositions of this theory, I shall commence by laying down the following definitions:—

Def. 1. A simple harmonic function is a function which varies as the sine or cosine of the independent variable, or of an angle varying in simple proportion with the independent variable. The harmonic curve is the well known name applied to the graphic representation, on the ordinary Cartesian system, of what I am now defining as a simple harmonic function. It is the form of a string vibrating in such a manner as to give the simplest and smoothest possible character of sound; and, in this case, the displacement of each particle of the string is a harmonic function of the time, besides being a harmonic function of the distance of its position of equilibrium from either end of the string. The sound in this case may be called a perfect unison.

Def. 2. The argument of a simple harmonic function is the angle to the sine or cosine of which it is proportional.

Cor. The argument of a harmonic function is equal to the independent variable multiplied by a constant factor, with a constant added; that is to say, it may be any linear function of the independent variable.

Def. 3. When time is the independent variable, the epoch is the interval which elapses from the era of reckoning till the function first acquires a maximum value. The augmentation of argument corresponding to that interval will be called "the epoch in angular measure," or simply "the epoch" when no ambiguity can exist as to what is meant.

Def. 4. The period of a simple harmonic function is the augmentation which the independent variable must receive to increase the argument by a circumference.

Cor. If c denote the coefficient of the independent variable in the argument,

the period is equal to $\frac{2\pi}{c}$. Thus, if T denote the period, ϵ the epoch in angular measure, and t the independent variable, the argument proper for a cosine is

$$\frac{2\pi t}{T}-\epsilon,$$

and the argument for a sine

$$\frac{2\pi t}{T}-\epsilon+\frac{\pi}{2}.$$

3. *Composition and Resolution of Simple Harmonic Functions of one Period.*

Prop. The sum of any two simple harmonic functions of one period is equal to one simple harmonic function whose amplitude is the diagonal of a parallelogram described upon lines drawn from one point to lengths equal to the amplitudes of the given functions, at angles measured from a fixed line of reference equal to their epochs, and whose epoch is the inclination of the same diagonal to the same line of reference.

Cor. 1. If A, A′ be the amplitudes of two simple harmonic functions of equal period, and ϵ, ϵ' their epochs; that is to say, if A cos $(mt-\epsilon)$, A′ cos $(mt-\epsilon')$ be two simple harmonic functions; the one simple harmonic function equal to their sum has for its amplitude and its epoch the following values respectively:—

(amplitude) $\{(A\cos\epsilon+A'\cos\epsilon')^2+(A\sin\epsilon+A'\sin\epsilon')^2\}^{\frac{1}{2}}$; or $\{A^2+2AA'\cos(\epsilon'-\epsilon)+A'^2\}^{\frac{1}{2}}$

(epoch) $$\tan^{-1}\frac{A\sin\epsilon+A'\sin\epsilon'}{A\cos\epsilon+A'\cos\epsilon'}.$$

Cor. 2. Any number of simple harmonic functions, of equal period, added together, are equivalent to a single harmonic function of which amplitude and epoch are derived from the amplitude and epochs of the given functions, in the same manner as the magnitude and inclination to a fixed line of reference, of the resultant of any number of forces in one plane, are derived from the magnitudes and the inclinations to the same line of reference of the given forces.

Cor. 3. The physical principle of the superposition of sounds being admitted, any number of simple unisons of one period co-existing, produce one simple unison of the same period, of which the intensity (measured by the square of the amplitude) and the epoch are determined in the manner just specified.

Cor. 4. The sum of any number of simple harmonic functions of one period vanishes for every argument, if it vanishes for any two arguments not differing by a semi-circumference, or by some multiple of a semi-circumference.

Cor. 5. The co-existence of perfect unisons may constitute perfect silence.

Cor. 6. A simple harmonic function of any epoch may be resolved into the sum of two whose epochs are respectively zero and a quarter period, and whose amplitudes are respectively equal to the value of the given function for the arguments zero and a quarter period respectively.

4. *Complex Harmonic Functions.*—Harmonic functions of different periods added, can never produce a simple harmonic function. If their periods are commensurable their sum may be called a complex harmonic function.

Cor. A complex harmonic function is the proper expression for a perfect harmony in music.

5. *Expressibility of Arbitrary Functions by Trigonometrical series.*

Prop. A complex harmonic function, with a constant term added, is the proper expression, in mathematical language, for any arbitrary periodic function.

6. *Investigation of the Trigonometrical Series expressing an Arbitrary Function.*—Any arbitrary periodic function whatever being given, the amplitudes and epochs of the terms of a complex harmonic function, which shall be equal to it for every value of the independent variable, may be investigated by the "method of indeterminate coefficients," applied to determine an infinite number of coefficients from an infinite number of equations of condition, by the assistance of the integral calculus, as follows:—

Let $F(t)$ denote the function, and T its period. We must suppose the value of $F(t)$ known for every value of t, from $t=o$ to $t=T$. Let M_0 denote the constant term, and let M_1, M_2, M_3, &c., denote the amplitudes, and ϵ_1, ϵ_2, ϵ_3, &c., the epochs of the successive terms of the complex harmonic functions by which it is to be expressed; that is to say, let these constants be such that

$$F(t)=M_0+M_1\cos\left(\frac{2\pi t}{T}-\epsilon_1\right)+M_2\cos\left(\frac{4\pi t}{T}-\epsilon_2\right)+M_3\cos\left(\frac{6\pi t}{T}-\epsilon_3\right)+\&c.$$

Then, expanding each cosine by the ordinary formula, and assuming

$$M_1\cos\epsilon_1=A_1,\ M_2\cos\epsilon_2=A_2,\ \&c.$$

$$M_1\sin\epsilon_1=B_1,\ M_2\sin\epsilon_2=B_2,\ \&c.$$

we have

$$F(t)=A_0+A_1\cos\frac{2\pi t}{T}+A_2\cos\frac{4\pi}{T}+A_3\cos\frac{6\pi t}{T}+\&c.$$

$$+B_1\sin\frac{2\pi t}{T}+B_2\sin\frac{4\pi t}{T}+B_3\sin\frac{6\pi t}{T}+\&c.$$

Multiplying each member by $\cos\frac{2i\pi t}{T}dt$ where i denotes o or any integer, and integrating from $t=o$ to $t=T$, we have,—

$$\int_o^T F(t)\cos\frac{2i\pi t}{T}dt=A_i\int_o^T\left(\cos\frac{2i\pi t}{T}\right)^2dt;$$

$$=A_i\times\tfrac{1}{2}T,\ \text{when } i \text{ is any integer};$$

or

$$=A_0\times T,\ \text{when } i=0.$$

Hence

$$A_0=\frac{1}{T}\int_o^T F(t)\,dt$$

$$A_i=\frac{2}{T}\int_o^T F(t)\cos\frac{2i\pi t}{T}\,dt;$$

and similarly we find $$B_i=\frac{2}{T}\int_o^T F(t)\sin\frac{2i\pi t}{T}\,dt:—$$

equations by which the coefficients in the double series of sines and cosines are expressed in terms of the values of the function supposed known from $t=o$ to $t=T$. The amplitudes and epochs of the single harmonic terms of the chief period and its submultiples are calculated from them, according to the following formula:—

$$\text{Tan}\,\epsilon_i=\frac{B_i}{A_i};\quad M_i=(A_i^2+B_i^2)^{\frac{1}{2}}$$

(or for logarithmic calculation, $M_i=A_i\sec\epsilon_i$).

The preceding investigation is sufficient as a solution of the problem,—to find a complex harmonic function expressing a given arbitrary periodic function, when once we are assured that the problem is possible; and when we have this assurance, it proves that the resolution is *determinate;* that is to say, that no other complex harmonic function than the one we have found can satisfy the conditions. For a thorough and most interesting analysis of the subject, supplying all that is wanting to complete the investigation, and giving admirable views of the problem from all sides, the reader is referred to FOURIER'S delightful treatise. A concise and perfect synthetical investigation of the harmonic expression of an arbitrary periodic function is to be found in POISSON'S "Theorie Mathématique de la Chaleur," chap. vii.

II.—*Periodic Variations of Terrestrial Temperature.*

7. If the whole surface of the earth were at each instant of uniform temperature, and if this temperature were made to vary as a perfectly periodic function of the time, the temperature at any internal point must ultimately come to vary also as a periodic function of the time, with the same period, whatever may have been the initial distribution of temperature throughout the whole. FOURIER'S principles show how the periodic variation of internal temperature is to be conceived as following, with diminished amplitude and retarded phase, from the varying temperature at the surface supposed given: and by his formulæ the precise law according to which the amplitude would diminish and the phase would be retarded, for points more and more remote from the surface, if the figure were truly spherical and the substance homogeneous, is determined.

8. The largest application of this theory to the earth as a whole is to the ana-

lysis of imaginable secular changes of temperature, with at least thousands of millions of years for a period. In such an application, it would be necessary to take into account the spherical figure of the earth as a whole. Periodic variations at the surface with any period less than a million* of years will, at points below the surface, give rise to variations of temperature not appreciably influenced by the general curvature, and sensibly agreeing with what would be produced if the surface were an infinite plane, except in so far as they are modified by superficial irregularities. Hence FOURIER's formulæ for an infinite solid, bounded on one side by an infinite plane, of which the temperature is made to vary arbitrarily, contain the proper analysis for diurnal or annual variations of terrestrial temperature, unless a theory of the effect of inequalities of surface (upon which no investigator has yet ventured) is aimed at.

9. The effect of diurnal variations of temperature becomes insensible at so small a distance below the surface, that in most localities irregularities of soil and drainage must prevent any very satisfactory theoretical treatment of their inward progression and extinction from being carried out. At depths exceeding three feet below the surface, all periodic effects of daily variations of temperature become insensible in most soils, and the observable changes are those due to a daily average, varying from day to day. If now the annual variation of temperature were truly periodic, a complex harmonic function could be determined to represent for all time the temperature at three feet or any greater depth. But in reality the annual variation is very far from recurring in a perfectly periodic manner, since there are both great differences in the annual average temperatures, and never-ceasing irregularities in the progress of the variation within each year. A full theory of the consequent variations of temperature propagated downwards, must include the consideration of non-periodic changes; but the most convenient first step is that which I propose to take in the present communication, in which the average annual variations for groups of years will be discussed according to the laws to which periodic variations are subject.

10. The method which FOURIER has given for treating this and other similar problems is founded on the principle of the independent superposition of thermal conductions. This principle holds rigorously in nature, except in so far as the

* A periodic variation of external temperature of one million years' period would give variations of temperature within the earth sensible to one thousand times greater depths than a similar variation of one year's period. Now the ordinary annual variation is reduced to $\frac{1}{20}$ of its superficial amount at a depth of 25 French feet, and is scarcely sensible at a depth of 50 French feet (being there reduced, in such rock as that of Calton Hill, to $\frac{1}{400}$). Hence, at a depth of 50,000 French feet, or about ten English miles, a variation having one million years for its period would be reduced to $\frac{1}{400}$. If the period were ten thousand million years, the variation would similarly be reduced to $\frac{1}{400}$ at 1000 miles' depth, and would be to some appreciable extent affected by the spherical figure of the whole earth, although to only a very small extent, since there would be comparatively but very little change of temperature (less than $\frac{1}{20}$ of the superficial amount) beyond the first layer of 500 miles' thickness.

conductivity or the specific heat of the conducting substance may vary with the changes of temperature to which it is subjected; and it may be accepted with very great confidence in the case with which we are now concerned, as it is not at all probable that either the conductivity or the specific heat of the rock or soil can vary at all sensibly under the influence of the greatest changes of temperature experienced in their natural circumstances; and, indeed, the only cause we can conceive as giving rise to sensible change in these physical qualities is the unequal percolation of water, which we may safely assume to be confined in ordinary localities to depths of less than three feet below the surface. The particular mode of treatment which I propose to apply to the present subject consists in expressing the temperature at any depth as a complex harmonic function of the time, and considering each term of this function separately, according to FOURIER's formulæ for the case of a simple harmonic variation of temperature, propagated inwards from the surface. The laws expressed by these formulæ may be stated in general terms as follows.

11. *Fourier's Solution stated.**—If the temperature at any point of an infinite plane, in a solid extending infinitely in all directions, be subjected to a simple harmonic variation, the temperature throughout the solid on each side of this plane will follow everywhere according to the simple harmonic law, with epochs retarded equally, and with amplitudes diminished in a constant proportion for equal augmentations of distance. The retardation of epoch expressed in circular measure (arc divided by radius) is equal to the diminution of the Napierian logarithm of the amplitude; and the amount of each per unit of distance is equal to $\sqrt{\frac{\pi c}{\mathrm{T}k}}$, if c denote the capacity for heat of a unit bulk of the substance, and k its conductivity.†

12. Hence, if the complex harmonic functions expressing the varying temperature at two different depths be determined, and each term of the first be compared with the corresponding term of the second, the value of $\sqrt{\frac{\pi c}{\mathrm{T}k}}$ may be determined either by dividing the difference of the Napierian logarithms of the amplitudes or the difference of the epochs by the distance between the points. The comparison of each term in the one series with the corresponding term in the other series gives us, therefore, two determinations of the value of $\sqrt{\frac{\pi c}{k}}$, which should agree perfectly, if (1) the data were perfectly accurate, if (2) the isothermal surfaces throughout were parallel planes, and if (3) the specific heat and conductivity of the soil were everywhere and always constant.

* For the mathematical demonstration of this solution, see Note appended to Professor EVERETT's paper, which follows the present article in the Transactions.

† That is to say, the quantity of heat conducted per unit of time across a unit area of a plate of unit thickness, with its two surfaces permanently maintained at temperatures differing by unity.

As these conditions are not strictly fulfilled in any natural application, the first thing to be done in working out the theory is to test how far the different determinations agree, and to judge accordingly of the applicability of the theory in the circumstances. If the test thus afforded prove satisfactory, the value of the conductivity in absolute measure may be deduced from the result with the aid of a separate experimental determination of the specific heat.

13. The method thus described differs from that followed by Professor FORBES in substituting the separate consideration of separate terms of the complex harmonic function for the examination of the whole variation unanalysed, which he conducted according to the plan laid down by POISSON.

This plan consists in using the formulæ for a simple harmonic variation, as approximately applicable to the actual variation. At great depths the amplitudes of the second and higher terms of the complex harmonic function become so much reduced as not sensibly to influence the variation, which is consequently there expressed with sufficient accuracy by a single harmonic term of yearly period; but at even the greatest depths for which continuous observations have actually been made, the second (or semi-annual) term has a very sensible influence, and the third and fourth terms are by no means without effect on the variations at three feet and six feet from the surface. A close agreement with theory is therefore not to be expected, until the method of analysis which I now propose is applied. It may be added, that in the theoretical reductions hitherto made, either by Professor FORBES or others, the amplitudes of the variations for the different depths have alone been compared, and the very interesting conclusion of theory, as to the relation between the absolute amount of retardation of phase and the diminution of amplitude for any increase of depth, has remained untested.

14. In Professor FORBES's paper,* the very difficult operations which he had performed for effecting the construction and the sinking of the thermometers, and the determination of the corrections to be applied to obtain the true temperatures of the earth at the different depths from the readings of the scales graduated on their stems protruding above the surface, are fully described. The results of five years' observations—1837 to 1842—are given, along with most interesting graphical representations and illustrations. A process of graphic interpolation, for estimating the temperatures at times intermediate between those of observations, is applied for the purpose of obtaining data from which the complex harmonic functions expressing the temperatures actually observed for the different depths are determined. I am thus indebted to Professor FORBES for the mode of procedure (described below) which I have myself followed in expressing the variations of temperature during the succeeding thirteen years for the Calton Hill

* Account of Some Experiments on the Temperature of the Earth at Different Depths and in Different Soils near Edinburgh; *Transactions* R.S.E., Vol. XVI. Part II. Edinburgh, 1846.

station (where alone the observations were continued). The only variation from his process which I have made is, that instead of taking twelve points of division for the yearly period I have taken thirty-two, with a view to obtaining a more perfect representation of all the features of the observed variations, and a more exact average for the principal terms, especially the annual and the semi-annual terms of the complex harmonic function expressing them.

15. *Application of the General Theory to Five Years' Observations*—1837 *to* 1842—*at* Professor FORBES's *three Thermometric Stations.*—The first application which I made of the analytical theory explained above, was to the harmonic terms which Professor FORBES had found for expressing the average annual progressions of temperature during the five years' term of observations at the three stations. These terms (which I have recalculated to get their values true to a greater number of significant figures), with alterations of notation which I have found convenient for the analytical expressions, are as follows:—

Three Feet below Surface.

Observatory, . . .	$45{\cdot}49 + 7{\cdot}39 \cos 2\pi(t - {\cdot}63) + 0{\cdot}362 \cos 2\pi(2t - {\cdot}669)$
Experimental Gardens,	$46{\cdot}13 + 9{\cdot}00 \cos 2\pi(t - {\cdot}616) + 0{\cdot}737 \cos 2\pi(2t - {\cdot}183)$
Craigleith, . . .	$45{\cdot}88 + 8{\cdot}16 \cos 2\pi(t - {\cdot}617) + 0{\cdot}284 \cos 2\pi(2t - {\cdot}154)$

Six Feet below Surface.

Observatory, . . .	$45{\cdot}86 + 5{\cdot}06 \cos 2\pi(t - {\cdot}686) + 0{\cdot}433 \cos 2\pi(2t - {\cdot}731)$
Experimental Gardens,	$46{\cdot}42 + 6{\cdot}66 \cos 2\pi(t - {\cdot}665) + 0{\cdot}501 \cos 2\pi(2t - {\cdot}182)$
Craigleith, . . .	$45{\cdot}92 + 6{\cdot}16 \cos 2\pi(t - {\cdot}649) + 0{\cdot}368 \cos 2\pi(2t - {\cdot}305)$

Twelve Feet below Surface.

Observatory, . . .	$46{\cdot}36 + 2{\cdot}44 \cos 2\pi(t - {\cdot}799) + 0{\cdot}075 \cos 2\pi(2t - {\cdot}833)$
Experimental Garden, .	$46{\cdot}76 + 3{\cdot}38 \cos 2\pi(t - {\cdot}782) + 0{\cdot}230 \cos 2\pi(2t - {\cdot}390)$
Craigleith, . . .	$45{\cdot}92 + 4{\cdot}22 \cos 2\pi(t - {\cdot}713) + 0{\cdot}067 \cos 2\pi(2t - {\cdot}819)$

Twenty-four Feet below Surface.

Observatory, . . .	$46{\cdot}87 + 0{\cdot}655 \cos 2\pi(t - 1{\cdot}013)$
Experimental Garden, .	$47{\cdot}09 + 0{\cdot}920 \cos 2\pi(t - {\cdot}986)$
Craigleith, . . .	$46{\cdot}07 + 1{\cdot}940 \cos 2\pi(t - {\cdot}849)$

The semi-annual terms in these equations present so great irregularities (those for the Calton Hill station, for instance, showing a greater amplitude at 6 feet deep than at 3 feet), that no satisfactory result can be obtained by including them in the theoretical discussion on which we are now about to enter. We shall see later, however, that when an average for the whole period of eighteen years for the Calton Hill station is taken, the semi-annual terms are, for the 3 feet and 6 feet depths, in fair agreement with theory; and for the two greater depths are as small as is necessary for the verification of the theory, and so small as to be much influenced by errors of observation and of reduction, or of "corrections" for temperature of the thermometer tubes. For the present, we attend exclusively to the annual terms. The amplitudes and epochs of these terms, extracted from the preceding equations, are shown in the following table:—

TABLE III.—ANNUAL HARMONIC VARIATIONS OF TEMPERATURE.

Depths below surface in French feet.	Calton Hill.			Experimental Garden.			Craigleith Quarry.		
	Amplitudes in degrees Fahr.	Epochs of Maximum.		Amplitudes in degrees Fahr.	Epochs of Maximum.		Amplitudes in degrees Fahr.	Epochs of Maximum.	
		In Degs. and Mins.	In Months and Days.		In Degs. and Mins.	In Months and Days.		In Degs. and Mins.	In Months and Days.
Feet.	°	°		°	°		°	°	
3	7·386	226 52′	Aug. 19	9·063	221 40′	Aug. 13	8·069	222 0′	Aug. 14
6	5·063	247 5′	Sept. 8	6·661	239 20′	31	6·148	233 43′	26
12	2·455	287 30′	Oct. 19	3·408	281 27′	Oct. 13	4·216	256 42′	Sept. 17
24	0·655	365 6′	Jan. 6	0·920	355 0′	Dec. 27	1·836	305 46′	Nov. 7

By taking the differences of the Napierian logarithms of the amplitudes, and the differences of epochs reduced to circular measure (arc divided by radius), thus shown for the different depths, and dividing each by the corresponding difference of depths, we find the following numbers.

TABLE IV.—RATES OF LOGARITHMIC DIMINUTION IN AMPLITUDE, AND OF RETARDATION IN EPOCH, OF ANNUAL HARMONIC VARIATIONS DOWNWARDS.

Depths below surface in French feet.	Calton Hill.		Experimental Garden.		Craigleith Quarry.	
	Rate of Diminution of Napierian Logarithm of Amplitude per foot of Descent.	Rate of Retardation of Epoch in Circular Measure, per foot of Descent.	Rate of Diminution of Napierian Logarithm of Amplitude per foot of Descent.	Rate of Retardation of Epoch in Circular Measure, per foot of Descent.	Rate of Diminution of Napierian Logarithm of Amplitude per foot of Descent.	Rate of Retardation of Epoch in Circular Measure, per foot of Descent.
3 to 6 feet.	·1259	·1176	·1004	·1163	·09372	·06399
6 to 12	·1206	·1176	·1130	·1193	·06304	·06690
12 to 24	·1101	·1129	·1084	·1062	·06476	·06690
3 to 24	·1154	·1149	·1082	·1114	·06841	·06648

16. All the numbers here shown for each station would be equal, if the conditions of uniformity supposed in the theoretical solution were fulfilled. The discrepancies are, with the exception of one of the numbers for Craigleith Quarry, on the whole small—smaller, indeed, than might be expected, when the very notable deviations of the true circumstances from the theoretical conditions are considered. The mean results over the 21 feet, shown in the last line, present very remarkable agreements: the numbers derived from amplitudes being identical with that derived from epochs for the Calton Hill station; while the differences between the corresponding numbers for the two other stations are in each case only about 3 per cent. Taking that one number for the first station, and the mean of the slightly differing numbers derived from amplitudes and from epochs respectively, for the second and third, we have undoubtedly very accurate determinations of the value of $\sqrt{\frac{\pi c}{k}}$ for the three stations, which are as follows:—

Calton Hill Trap Rock.	Experimental Garden Sand.	Craigleith Quarry Sandstone.
$\sqrt{\frac{\pi c}{k}} = \cdot 1154$	$\sqrt{\frac{\pi c}{k}} = \cdot 1098$	$\sqrt{\frac{\pi c}{k}} = \cdot 06744$

A continuation of the observations at Calton Hill not only leads, as we shall see, to almost identical results, both by diminution of amplitude and by retardation, on the whole 21 feet, but also reproduces some of the features of discrepance presented by the progress of the variation through the intermediate depths; and therefore confirms the general accuracy of the preceding results, for all the stations, so far as it might be questioned because of only five years' observations having been available. Further consideration of these results, and deduction of the conductivities of the different portions of the earth's crust involved, is deferred until after we have taken into account the farther data for Calton Hill, to the reduction of which we now proceed.

17. *Application to Thirteen Years' Observations* (1842–1854) *at the Thermometric Station, Calton Hill.*—The observations on thermometers fixed by Professor Forbes at the different depths in the rock of Calton Hill, have been regularly continued weekly till the present time by the staff of the Royal Edinburgh Observatory, and regularly corrected to reduce to true temperatures of the bulbs, on the same system as before. Tables of these corrected observations, for the twelve years 1842 to 1854 inclusive, having been supplied to me through the kindness of Professor Piazzi Smyth, I have had the first five terms of the harmonic expression for each year determined in the following manner:*—In the first place, the observations were laid down graphically, and an interpolating curve drawn through the points, according to the method of Professor Forbes. The four curves thus obtained represent the history of the varying temperature at the four different depths respectively, as completely and accurately as it can be inferred from the weekly observations. The space corresponding to each year was then divided into 32 equal parts (the first point of division being taken at the beginning of the year), and the corresponding temperatures were taken from the curve. The co-efficients of the double harmonic series (cosines and sines) for each year were calculated from these data, with the aid of the forms given by Mr Archibald Smith, and published by the Board of Admiralty, for deducing the harmonic expression of the error of a ship's compass from observations on the 32 points. The general form of the harmonic expression being written thus—

$$V = A_0 + A_1 \cos 2\pi t + B_1 \sin 2\pi t + A_2 \cos 4\pi t + B_2 \sin 4\pi t + \&c.,$$

where V denotes the varying temperature to be expressed, and t the time, in terms of a year as unit. The following table shows the results which were obtained, with the exception of the values of A_0:—

* The operations here described, involving, as may be conceived, no small amount of labour, were performed by Mr D. M'Farlane, my laboratory assistant, and Mr J. D. Everett, now Professor of Mathematics and Natural Philosophy in King's College, Windsor, N.S.

TABLE V.

Year.	Feet.	A_1.	B_1.	A_2.	B_2.	A_3.	B_3.	A_4.	B_4.
1842	3	−6·19	−5·00	+ ·01	+ ·25	+ ·60	+ ·06	+ ·23	− ·71
	6	−2·85	−4·80	− ·15	+ ·03	+ ·10	+ ·10	+ ·12	− ·26
	12	+ ·34	−2·73	− ·12	− ·13	− ·08	− ·04	+ ·01	− ·04
	24	+ ·68	− ·14	·00	− ·07	− ·02	− ·04	− ·01	− ·02
1843	3	−4·75	−5·11	+ ·17	+ ·91	+1·23	+ ·30	+ ·79	− ·17
	6	−1·63	−4·38	− ·20	+ ·61	+ ·45	+ ·42	+ ·32	− ·30
	12	+ ·83	−2·04	− ·18	− ·08	− ·05	+ ·17	− ·03	+ ·10
	24	+ ·62	+ ·12	·00	− ·02	− ·01	− ·01	·00	·00
1844	3	−5·29	−4·53	− ·05	+ ·70	+ ·74	+ ·71	+ ·08	+ ·49
	6	−2·11	−4·09	+ ·22	+ ·50	+ ·20	+ ·50	− ·06	+ ·20
	12	+ ·52	−2·15	+ ·18	+ ·05	+ ·11	+ ·13	− ·05	− ·01
	24	+ ·59	− ·02	− ·03	− ·02	·00	− ·03	− ·01	− ·02
1845	3	−5·17	−5·01	− ·17	+ ·56	+ ·67	+ ·29	− ·28	+ ·02
	6	−2·02	−4·38	+ ·07	+ ·30	·00	+ ·18	− ·04	− ·08
	12	+ ·63	−2·15	+ ·12	+ ·06	− ·01	− ·03	·00	+ ·02
	24	+ ·65	+ ·13	+ ·04	·00	+ ·01	+ ·02	+ ·01	+ ·02
1846	3	−5·65	−5·17	+ ·03	+1·05	− ·86	+ ·64	+ ·00	− ·49
	6	−2·37	−4·64	− ·38	+ ·44	− ·63	− ·39	− ·11	− ·22
	12	+ ·47	−2·70	− ·30	− ·17	− ·14	− ·45	·00	− ·07
	24	+ ·64	− ·22	− ·02	− ·17	+ ·03	− ·11	− ·03	− ·06
1847	3	−5·36	−5·31	+ ·69	+ ·24	− ·18	− ·81	− ·02	− ·14
	6	−2·08	−4·58	+ ·18	+ ·32	+ ·11	− ·39	− ·05	− ·04
	12	+ ·70	−2·37	− ·03	+ ·17	+ ·12	+ ·14	+ ·03	+ ·02
	24	+ ·66	+ ·16	− ·01	+ ·04	+ ·01	+ ·03	+ ·01	+ ·03
1848	3	−5·83	−4·46	+ ·33	+ ·27	+ ·29	+ ·35	+ ·45	− ·30
	6	−2·32	−4·16	+ ·13	+ ·27	+ ·02	+ ·23	+ ·28	+ ·09
	12	+ ·56	−2·15	+ ·04	+ ·16	− ·01	+ ·09	+ ·04	+ ·11
	24	+ ·66	+ ·10	− ·01	+ ·03	·00	+ ·02	− ·01	+ ·01
1849	3	−4·56	−4·44	+ ·05	+1·14	− ·66	− ·10	− ·48	− ·69
	6	−1·85	−3·97	− ·20	+ ·45	− ·28	− ·15	+ ·01	− ·25
	12	+ ·49	−2·06	− ·23	+ ·04	+ ·04	− ·06	+ ·09	− ·05
	24	+ ·57	+ ·03	·00	− ·02	+ ·01	+ ·02	·00	+ ·01
1850	3	−5·40	−4·50	− ·12	+ ·70	− ·54	− ·82	− ·15	− ·42
	6	−2·43	−4·15	− ·22	+ ·31	+ ·03	− ·47	+ ·11	− ·17
	12	+ ·17	−2·27	− ·15	− ·04	− ·10	− ·05	+ ·04	+ ·01
	24	+ ·61	− ·04	+ ·01	− ·03	+ ·01	·00	− ·01	− ·01
1851	3	−4·18	−4·53	+ ·12	+ ·96	− ·09	+ ·31	+ ·22	+ ·18
	6	−1·65	−3·92	− ·19	+ ·53	− ·18	+ ·07	− ·03	+ ·14
	12	+ ·61	−1·99	− ·22	+ ·01	− ·04	− ·06	− ·05	− ·02
	24	+ ·56	+ ·02	+ ·01	− ·05	·00	− ·01	− ·14	− ·01
1852	3	−4·92	−4·80	+ ·20	+1·32	+ ·64	− ·24	− ·46	+ ·31
	6	−1·87	−4·25	− ·23	+ ·71	+ ·15	+ ·10	− ·31	− ·02
	12	+ ·54	−2·24	− ·26	+ ·05	+ ·01	+ ·09	− ·01	− ·07
	24	+ ·61	− ·03	− ·12	− ·07	− ·01	− ·04	·00	− ·02
1853	3	−5·08	−5·43	+ ·83	+ ·30	+ ·11	+ ·27	+ ·18	+ ·19
	6	−1·92	−4·57	+ ·38	+ ·41	− ·05	+ ·17	+ ·06	+ ·13
	12	+ ·76	−3·15	− ·01	+ ·21	− ·01	·00	− ·01	+ ·03
	24	+ ·62	+ ·18	− ·39	+ ·03	·00	+ ·10	+ ·01	+ ·03
1854	3	−5·69	−4·56	− ·61	+ ·53	·00	− ·15	+ ·15	− ·20
	6	−2·48	−4·27	− ·50	− ·01	·00	− ·13	+ ·08	− ·03
	12	+ ·42	−2·31	− ·12	− ·21	+ ·02	− ·03	+ ·02	+ ·01
	24	+ ·63	− ·03	+ ·02	− ·02	·00	− ·01	− ·01	− ·01
Average for 13 years—1842 to '54.	3	−5·236	−4·835	+ ·114	+ ·687	+ ·150	+ ·0778	+ ·05462	− ·14846
	6	−2·122	−4·320	− ·0838	+ ·375	− ·00615	+ ·0185	+ ·02923	− ·01615
	12	+ ·5415	−2·332	− ·0985	+ ·00923	− ·01846	− ·00778	+ ·006154	+ ·003078
	24	+ ·6231	− ·0200	− ·0385	− ·0285	− ·00231	− ·00462	− ·01462	− ·003846

The values which were found for A_0 should represent the annual mean temperatures. They differ slightly from the annual means shown in the Royal Observatory Report, which, derived as they are from a direct summation of all the weekly observations, must be more accurate. The variations, and the final average values of these annual means, present topics for investigation of the highest interest and importance, as I have remarked elsewhere (see British Association's Report, section A, Glasgow, 1855); but as they do not belong to the special subject of the present paper, their consideration must be deferred to a future occasion.

18. *Theoretical Discussion.*—The mean value of the coefficients in the last line of the table, being obtained from so considerable a number of years, can be but very little influenced by irregularities from year to year, and must therefore correspond to harmonic functions for the different depths, which would express truly periodic variations of internal temperature consequent upon a continued periodical variation of temperature at the surface.

19. According to the principle of the superposition of thermal conductions, the difference between this continuous harmonic function of five terms for any one of the depths, and the actual temperature there at the corresponding time of each year, would be the real temperature consequent upon a certain real variation of superficial temperature. Hence the coefficients shown in the preceding table afford the data, first by their mean values, to test the theory explained above for simple harmonic variations, and to estimate the conductivity of the soil or rock, as I propose now to do; and secondly, as I may attempt on a future occasion, to express analytically the residual variations which depend on the inequalities of climate from year to year, and to apply the mathematical theory of conduction to the nonperiodic variations of internal temperature so expressed.

20. Let us, accordingly, now consider the complex harmonic functions corresponding to the mean coefficients of the preceding table, and, in the first place, let us reduce the double harmonic series in each case to series in each of which a single term represents the resultant simple harmonic variation of the period to which it corresponds, in the manner shown by the proposition and formulæ of § 3 above.

21. On looking to the annual and semi-annual terms of the series so found, we see that their amplitudes diminish, and their epochs of maximum augment, with considerable regularity, from the less to the greater depths. The following table shows, for the annual terms, the logarithmic rate of diminution of the amplitudes, and the rate of retardation of the epoch between the points of observation in order of depth:—

TABLE VI.—AVERAGE OF THIRTEEN YEARS, 1842 TO 1854; TRAP ROCK OF CALTON HILL.

Depths below surface, in French feet.	Diminution of Napierian logarithm of amplitude per French foot of descent.	Retardation of epoch in circular measure, per French foot of descent.
3 to 6 feet	·1310	·1233
6 to 12 „	·1163	·1140
12 to 24 „	·1121	·1145
3 to 24 feet	·1160	·1156

22. The numbers here shown would all be the same, if the conditions of uniformity supposed in the theoretical solution were fulfilled. Although, as in the previous comparisons, the agreement is on the whole better than might have been expected, there are certainly greater differences than can be attributed to errors of observation. Thus, the means of the numbers in the two columns are for the three different intervals of depth in order as follows:—

	Mean deductions from amplitude and epoch.
3 to 6 feet, ...	·127
6 to 12 „	·115
12 to 24 „	·113

—numbers which seem to indicate an essential tendency to diminish at the greater depths. This tendency is shown very decidedly in each column separately; and it is also shown in each of the corresponding columns, in tables given above, of results derived from Professor Forbes' own series of a period of five years.

23. There can be no doubt but that this discrepance is not attributable to errors of observation, and it must therefore be owing to deviation in the natural circumstances from those assumed for the foundation of the mathematical formulæ. In reality, none of the conditions assumed in FOURIER's solution is rigorously fulfilled in the natural problem; and it becomes a most interesting subject for investigation to discover to what particular violation or violations of these conditions the remarkable and systematic difference discovered between the deductions from the formula and the results of observation is due. In the first place, the formula is strictly applicable only to periodic variations, and the natural variations of temperature are very far from being precisely periodic; but if we take the average annual variation through a sufficiently great number of years, it may be fairly presumed that irregularities from year to year will be eliminated; and that the discrepance we have now to explain does not depend on residual inequalities of this kind seems certain, from the fact that it exists in the average

of Professor Forbes' first five years' series no less decidedly than in that of the period of thirteen years following.

24. For the true explanation we must therefore look either to inequalities (formal or physical) in the surface at the locality, or to inequalities of physical character of the rock below. It may be remarked, in the first place, that if the rates of diminution of logarithmic amplitude and of retardation of epoch, while less, as they both are, at the greater depths, remained exactly equal to one another, the conductivity must obviously be greater, and the specific heat less in the same proportion inversely, at the greater depths. For in that case, all that would be necessary to reconcile the results of observation with FOURIER's formula, would be to alter the scale of measurement of depths so as to give a nominally constant rate of diminution of the logarithmic amplitude and of the retardation of epoch; and the physical explanation would be, that thicker strata at the greater depths, and thinner strata at the less depths (all of equal horizontal area), have all equal conducting powers and equal thermal capacities.*

25. Now, in reality, a portion, but only a portion, of the discrepance may be done away with in this manner; for while the logarithmic amplitudes and the epochs each experience a somewhat diminished rate of variation per French foot of descent at the greater depths, this diminution is much greater for the former than for the latter; so that although the mean rates per foot on the whole 21 feet are as nearly as possible equal for the two, being ·1160 for the logarithmic amplitudes, and ·1156 for the epoch), the rate of variation of the logarithmic amplitude exceeds that of the epoch by about 6 per cent., on the average of the stratum 3 to 6 feet; and falls short of it by somewhat more than 2 per cent., in the lower stratum, 12 to 24 feet. To find how much of the discrepance is to be explained by the variation of conductivity and specific heat in inverse proportion to one another at the different depths, we may take the mean of the rates of variation of logarithmic amplitude and of epoch at each depth, and alter the scale of longitudinal reckoning downwards, so as to reduce the numerical measures of these rates to equality. This, however, we shall not do in either the five years' or the thirteen years' term, which we have hitherto considered separately, but for a harmonic annual variation representing the average of the whole eighteen years 1837 to 1854.

* The "conducting power" of a solid plate is an expression of great convenience, which I define as the quantity of heat which it conducts per unit of time, when its two surfaces are permanently maintained at temperatures differing by unity. In terms of this definition, the specific conductivity of a substance may be defined as the conducting power per unit area of a plate of unit thickness. The conducting power of a plate is calculated by multiplying the number which measures the specific conductivity of its substance by its area, and dividing by its thickness.

The *thermal capacity of a body* may be defined as the quantity of heat required to raise its mass by a unit (or one degree) of temperature. The specific heat of a substance is the thermal capacity of a unit quantity of it, which may be either a unit of weight or a unit of bulk.

26. By taking, for each depth, the coefficients A_1, B_1 (not explicitly shown above), derived from the first five years' average, and multiplying by 5; taking similarly the coefficients A_1, B_1, for the succeeding thirteen years' average, and multiplying by 13; adding each of the former products to the corresponding one of the latter, and dividing by 18; we obtain, as the proper average for the whole eighteen years, the values shown in the following table, in the columns headed A_1, B_1. The amplitudes and epochs shown in the next columns are deduced from these by the formulæ $\sqrt{(A_1^2+B_1^2)}$ and $\tan^{-1}\frac{B_1}{A_1}$ respectively,—

TABLE VII.—ANNUAL HARMONIC VARIATION OF TEMPERATURE IN CALTON HILL, FROM 1837 TO 1844 INCLUSIVE.

Depths.	A_1 In degrees Fahr.	B_1 In degrees Fahr.	Amplitudes in degrees Fahr.	Epochs in degrees and minutes.
3 feet	$-5{\cdot}184$°	$-4{\cdot}989$°	$7{\cdot}1949$°	223° 54′
6 feet	$-2{\cdot}080$	$-4{\cdot}416$	$4{\cdot}8812$	244 47
12 feet	$+\ {\cdot}5961$	$-2{\cdot}3345$	$2{\cdot}4094$	284 19
24 feet	$+\ {\cdot}6311$	$+\ {\cdot}0306$	$\cdot6319$	362 47

From these, as before, for ten terms of five years and of thirteen years separately, we deduce the following:—

TABLE VIII.—AVERAGE OF EIGHTEEN YEARS, 1837 TO 1844; TRAP ROCK OF CALTON HILL.

Depths below surface, in French feet.	Diminution of Logarithmic Amplitude per French foot of Descent.	Retardation of Epoch in Circular Measure, per French foot of Descent.
3 to 6 feet.	·1286	·1215
6 to 12 „	·1177	·1150
12 to 24 „	·1115	·1141
3 to24 feet.	·1157	·1154

27. Hence, we have as final means, of effects on logarithmic amplitudes and on epochs, for the average annual variation on the whole period of eighteen years,—

1. From depth 3 feet to 6 feet, ... ·1250
2. „ 6 „ 12 „ . . . . ·1163
3. „ 12 „ 24 „ . . . . ·1128

If now, in accordance with the proposed plan, we measure depths, not in constant

units of length, but in terms of thicknesses corresponding to equal conducting powers and thermal capacities, and if we continue to designate the thickness of the first stratum by its number 3 of French feet, our reckoning for the positions of the different thermometers will stand as follows:—

TABLE IX.

Thermometers numbered downwards.	Depths in true French feet, below No. 1.	Depths in Terms of Conductive Equivalents.
I.	0	0
II.	3	3
III.	9	$3+\frac{\cdot 1163}{\cdot 1250}\times 6=8\cdot 58$
IV.	21	$8\cdot 58+\frac{\cdot 1128}{\cdot 1250}\times 12=19\cdot 41$

According to this way of reckoning depths, we have the following rates of variation of the logarithmic amplitudes, and of the epochs separately, reduced from the previously stated means for the whole period of eighteen years:—

TABLE X.

Portions of Rock.	Rates of Diminution of Logarithmic Amplitude per French foot, and Conductive Equivalents.	Rate of Retardation of Epoch per French foot, and Conductive Equivalents.
Between Thermometers Nos. I. and II.	·1286	·1215
,, ,, II. and III.	·1265	·1236
,, ,, III. and IV.	·1236	·1264
Between Thermometers Nos. I. and IV.	·1252	·1248

28. Comparing this Table with the preceding Table VIII., we see that the discrepancies are very much diminished; and we cannot doubt but that the conductive power of the rock is less in the lower parts of the rock, and that the amount of the variation is approximately represented by Table IX. We have, however, in Table X. still too great discrepancies to allow us to consider variation in the value of kc, as the only appreciable deviation from FOURIER's conditions of uniformity.

29. In endeavouring to find whether these residual discrepancies are owing to

variations of k and c not in inverse proportion one to the other, I have taken FOURIER's equation

$$c\frac{dv}{dt}=k\frac{d^2v}{dx^2}+\frac{dk}{dx}\frac{dv}{dx},$$

where v denotes the temperature at time t, and at a distance x from an isothermal plane of reference (a horizontal plane through thermometer No. I., for instance); k the conductivity, varying with x; and c the capacity for heat of a unit of volume, which may also vary with x. In this equation I have taken

$$v=a\epsilon^{-\mathrm{P}}\cos\left(\frac{2\pi t}{\mathrm{T}}-\mathrm{Q}\right),$$

where P and Q are functions of x, assumed so as to express as nearly as may be the logarithmic amplitudes, and the epochs, deduced from observation. I have thus obtained two equations of condition, from which I have determined k and c, as functions of x. The problem of finding what must be the conductivity and the specific heat at different depths below the surface, in order that, with all the other conditions of uniformity perfectly fulfilled, the annual harmonic variation may be exactly that which we have found on the average of the eighteen years' term at Calton Hill, is thus solved. The result is, however, far from satisfactory. The small variations in the values of P and Q which we have found in the representation of the observed temperatures, require very large and seemingly unnatural variations in the values of k and c.

30. I can only infer that the residual discrepancies from FOURIER's formula shown in Table X. are not with any probability attributable to variations of conductivity and specific heat in the rock, and conclude that they are to be explained by irregularities, physical and formal, in the surface. It is possible, indeed, that thermometric errors may have considerable influence, since there is necessarily some uncertainty in the corrections estimated for the temperatures of the different portions of the columns of liquid above the bulbs; and before putting much confidence in the discrepancies we have found, as true expressions of the deviations in the natural circumstances from FOURIER's conditions, a careful estimate of the probable or possible amount of error in the observed temperatures should be made. That even with perfect *data* of observation, as great discrepancies should still be found in final reductions such as we have made, need not be unexpected when we consider the nature of the locality, which is described by Professor FORBES in the following terms:—

The position chosen for placing the thermometer was below the surface "in the Observatory enclosure on the Calton Hill, at a height of 350 feet above the sea. The rock is a porphyritic trap, with a somewhat earthy basis, dull and tough fracture. *The exact position is a few yards east of the little transit house.* There are *also other buildings in the neighbourhood.* The ground rises slightly to

the east, and *falls abruptly to the west at a distance of fifteen yards.* The immediate surface is flat, *partly covered with grass, partly with gravel.*"*

I have marked by italics those passages which describe circumstances such as it appears to me might account for the discrepancies in question.

31. *Application to Semi-annual Harmonic Terms.*—The harmonic expressions given above (§ 15) for the average periodic variations for the three stations of Professor FORBES' original series of five years' observations, contain semi-annual terms, which are obviously not in accordance with theory. The retardations of epochs and the diminutions of amplitudes are, on the whole, too irregular to be reconcileable by any supposition as to the conductivities and specific heat of the soils and rocks involved, or as to the possible effects of irregularity of surface; and in two of the three stations, the amplitude of the semi-annual term is actually greater as found for the six feet deep than for the three feet deep thermometer, which is clearly an impossible result. The careful manner in which the observations have been made and corrected, seems to preclude the supposition that these discrepancies, especially for the three feet and six feet thermometers, for which the amplitudes of the semi-annual terms are from $\cdot 28^\circ$ to $\cdot 74^\circ$ (corresponding to variations of double those amounts, or from $\cdot 56^\circ$ to $1^\circ \cdot 48$), can be attributed to errors in the *data*. It must be concluded, therefore, that the semi-annual terms of those expressions do not represent any truly periodic elements of variation, and that they rather depend on irregularities of temperature in the individual years of the term of observation. Hence, until methods for investigating the conduction inwards of non-periodic variations of temperature are applied, we cannot consider that the special features of the progress of temperature during the five years' period at the three stations, from which our apparent semi-annual terms have been derived, have been theoretically analysed. But, as we have seen, every irregularity depending on individual years is perfectly eliminated when the average annual variation over a sufficiently great number of years is taken. Hence it becomes interesting to examine particularly the semi-annual terms for the eighteen years' average of the Calton Hill thermometers, which we now proceed to do.

32. Calculating as above (§ 26), for the coefficients A_1, B_1, the average values of A_2 and B_2, from Professor FORBES' results for his first five years' term, and from the averages for the next thirteen years shown in Table V. above, we find the values of A_2 and B_2 shown in the following table. The amplitudes and epochs are deduced as usual by the formulæ $\sqrt{\left(A_2^2+B_2^2\right)}$ and $\tan^{-1}\frac{B_2}{A_2}$. These reductions I only make for the three feet deep and the six feet deep thermometers, since, for the two others, as may be judged by looking at the thirteen years' average, shown in the former table, the amounts of the semi-annual varia-

* Professor FORBES on the Temperature of the Earth, *Trans.* R.S.E., 1846, p. 194.

tion do not exceed the probable errors in the data of observation sufficiently to allow us to draw any reliable conclusions from their apparent values.

TABLE XI.—AVERAGE SEMI-ANNUAL HARMONIC TERM, FROM EIGHTEEN YEARS' OBSERVATIONS AT CALTON HILL.

Depths below surface, in French feet.	A_2 In degrees Fahr.	B_2 In degrees Fahr.	Amplitudes In degrees Fahr.	Epochs in degrees and minutes.
3 feet.	°·1518	°·5842	°·604	°·75 26′
6 feet.	·0461	·3911	·394	96 43

The ratio of diminution of the amplitude here is $\frac{\cdot 604}{\cdot 394}$ or 1·53, of which the Napierian logarithm is ·426. Dividing this by 3, we find

·142

as the rate of diminution of the logarithmic amplitude per French foot of descent.

The retardation of epoch shown is 21° 17′; and therefore the retardation per French foot of descent is 7° 6′, or, in circular measure,

·1239.

If the data were perfect for a periodical variation, and the conditions of uniformity supposed in FOURIER's solution were fulfilled, these two numbers would agree, and each would be equal to $\sqrt{\frac{2\pi k}{c}}$. Hence, dividing them each by $\sqrt{2}$, we find

Apparent values of $\sqrt{\frac{\pi c}{k}}$	
·100	(by amplitudes)
·877	(by epochs).

The true value of $\sqrt{\frac{\pi c}{k}}$ must, as we have seen, be ·116, to a very close degree of approximation.

33. When we consider the character of the reduction we have made, and remember that the data were such as to give no semblance of a theoretical agreement when the first five years' term of observations was taken separately, we may be well satisfied with the approach to agreement presented by these results, depending as they do on only eighteen years in all, and we may expect that, when the average is of a still larger term of observation, the discrepancies will be much diminished. In the mean time, we may regard the semi-annual term we have found for the three feet deep thermometer as representing a true feature of the yearly vicissitude; and it will be surely interesting to find whether it is a constant feature for the locality of Edinburgh, to be reproduced on averages of subsequent terms of observation.

34. It may be remarked, that the nearer to the equator is the locality, the

greater relatively will be the semi-annual term; that within the tropics the semi-annual term may predominate, except at the great depths; and that at the equator the tendency is for the annual term to disappear altogether, and to leave a semi-annual term as the first in a harmonic expression of the yearly vicissitude of temperature. The facilities which underground observation affords for the analysis of periodic variations of temperature, when the method of reduction which I have adopted is followed, will, it is to be hoped, induce those who have made similar observations in other localities to apply the same kind of analysis to their results; and it is much to be desired, that the system of observing temperatures at two if not more depths below the surface may be generally adopted at all meteorological stations, as it will be a most valuable means for investigating the harmonic composition of the annual vicissitudes.

III.—*Deduction of Conductivities.*

35. Notwithstanding the difficulty we have seen must attend any attempt to investigate all the circumstances which must be understood in order to reconcile perfectly the observed results with theory, the general agreement which we have found is quite sufficient to allow us to form a very close estimate of the ratio of the conductivity of the rock to its specific heat per unit of bulk. Thus, according to the means deduced from the whole period of eighteen years' observation, the average rate of variation of the logarithmic amplitude of the annual term through the whole space of twenty-one feet is ·1157, and of the epoch of the same term, ·1154. The mean of these, or ·1156, can differ but very little from the true average value of $\sqrt{\frac{\pi c}{k}}$ for the portion of rock between the extreme thermometers.

36. Dividing π by the square of the reciprocal of this number, we find 235·1 as the value of $\frac{k}{c}$, or, as we may call it, the conductivity of the rock in terms of the thermal capacity of a cubic foot of its own substance. In other words, we infer that all the heat conducted in a year (the unit of time) across each square foot of a plate one French foot thick, with its two sides maintained constantly at temperatures differing by 1°, would, if applied to raise the temperature of portions of the rock itself, produce a rise of 1° in 235 cubic feet. As it is difficult (although by no means impossible) to imagine circumstances in which the heat, regularly conducted through a stratum maintained, with its two sides, at perfectly constant temperatures, could be applied to *raise* the temperatures of other portions of the same substance, we may vary the statement of the preceding result, and obtain the following completely realisable illustration.

37. Let a large plate of the rock, everywhere one French foot thick, have every part of one of its sides (which, to avoid circumlocution, we shall call its lower side) maintained at one constant temperature, and let portions of homo-

geneous substance, at a temperature 1° lower, be continually placed in contact with the upper surface, and removed to be replaced by other homogeneous portions at the same lower temperature, as soon as the temperature of the matter actually thus applied rises in temperature by $\frac{1}{1000}$ of a degree. If this process is continued for a year, the whole quantity of the refrigerating matter thus used to carry away the heat conducted through the stratum must amount to 235,000 cubic feet for each square foot of area, which will be at the rate of ·00745 of a cubic foot per second. We may therefore imagine the process as effected by applying an extra stratum ·00745 of a foot thick every second of time. This extra stratum, after lying in contact for one second, will have risen in temperature by $\frac{1}{1000}$ of a degree. By means of the information contained in this apparently unpractical statement, many interesting problems may be practically solved, as I hope to show in a subsequent communication.

38. The value of $\sqrt{\frac{\pi c}{k}}$, derived from the whole eighteen-years period of observation (·1156), differs so little from that (·1154) found previously (§ 16) from Professor Forbes's observations and reductions of the first five of the years, that we may feel much confidence in the accuracy of the values ·1098 and ·06744, which, from his five years' data alone, we found (§ 16) for the corresponding constant with reference to the sand at the Experimental Garden and the sandstone of Craigleith Quarry. From them, calculating as above (§ 36), we find 260·5 and 690·7 as the values of $\frac{k}{c}$ for the terrestrial substances of these localities respectively; results of which the meaning is illustrated by the statements of §§ 36 and 37.

39. To deduce the conductivities of the strata, in terms of uniform thermal units, Professor Forbes had the "specific heats" of the substances determined experimentally by M. Regnault. The results, multiplied by the specific gravities, gave for the thermal capacities of portions of the three substances, in terms of that of an equal bulk of water, the values ·5283, ·3006, and ·4623 respectively. Now, these must be the values of c, if the thermal unit in which k is measured is the thermal capacity of a French cubic foot of water. Multiplying the values of $\frac{k}{c}$ found above by these values of c, we find for k the following values:—

Trap-rock of Calton Hill.	Sand of Experimental Gardens.	Sandstone of Craigleith.
124·2	78·31	319·3

The values found by Professor Forbes were—

111·2	82·6	298·3

Although many comparisons have been made between the conducting powers of different substances, scarcely any data as to thermal conductivity in absolute measure have been hitherto published, except these of Professor Forbes, and pro-

bably none approaching to their accuracy. The slightly different numbers to which we have been led by the preceding investigation are no doubt still more accurate.

40. To reduce these results to any other scale of linear measurement, we must clearly alter them in the inverse ratio of the square of the absolute lengths chosen for the units.* The length of a French foot being 1·06575 of the British standard foot, we must therefore multiply the preceding numbers by 1·13581, to reduce them to convenient terms.

41. We may, lastly, express them in terms of the most common unit, which is the quantity of heat required to raise the temperature of a grain of water by 1°; and to do this we have only to multiply each of them by $7000 \times 62{\cdot}447$, being the weight of a cubic foot in grains.

42. The following table contains a summary of our results as to conductivity expressed in several different ways, one or other of which will generally be found convenient:—

TABLE XII.—THERMAL CONDUCTIVITIES OF EDINBURGH STRATA, IN BRITISH ABSOLUTE UNITS [UNIT OF LENGTH, THE ENGLISH FOOT].

Description of Terrestrial Substance.	Conductivities in Terms of Thermal Capacity of Unit Bulk of Substance $\left(\frac{k}{c}\right)$.			Conductivities in Terms of Thermal Capacity of Unit Bulk of Water (k).			Conductivities in Terms of Thermal Capacity of One Grain of Water.
	Per Ann.	Per 24^h.	Per Second.	Per Ann.	Per 24_h.	Per Second.	Per Second.
Trap-rock of Calton Hill,	267·0	·7310	·000008461	141·1	·3863	·000004471	1·9544
Sand of Experimental Garden,	295·9	·8100	·000009375	88·9	·2435	·000002818	1·2319
Sandstone of Craigleith Quarry,	784·5	2·1478	·00002486	362·7	·9929	·00001149	5·0225

43. The statements (§§ 36 and 37) by which the signification of $\frac{k}{c}$ has been defined and illustrated, require only to have *cubic feet of water* substituted for

* Because the absolute amount of heat flowing through the plate across equal areas will be inversely as the thickness of the plate; and the effect of equal quantities of heat in raising the temperature of equal areas of the water will be inversely as the depth of the water. The same thing may be perhaps more easily seen by referring to the elementary definition of thermal conductivity (footnote to § 11, above). The absolute quantity of heat conducted across unit area of a plate of unit thickness, with its two sides maintained at temperatures differing by always the same amount, will be directly as the areas, and inversely as the thickness, and therefore simply as the absolute length chosen for unity. But the thermal unit in which these quantities are measured, being the capacity of a unit bulk of water, is directly as the cube of the unit length, and therefore the numbers expressing the quantities of heat compared will be inversely as the cubes of the lengths chosen for unity, and directly as these simple lengths: that is to say, finally, they will be inversely as the squares of these lengths.

cubic feet of rock, in their calorimetric specifications, to be applicable similarly to define and illustrate the meaning of the conductivity denoted by k. The fluidity of the water allows a modified and somewhat simpler explanation, equivalent to that of § 36, to be now given, as follows:—

44. If a long rectangular plate of rock, one foot thick, in a position slightly inclined to the horizontal, have water one foot deep flowing over it in a direction parallel to its length, and if the lower surface of the plate be everywhere kept 1° higher in temperature than the upper, the water must flow at the rate of k times the length of the plate per unit of time, in order that the heat conducted through the plate may raise it just 1° in temperature in its flow over the whole length. [It must be understood here, that the plate becomes warmer, on the whole, under the lower parts of the stream of water, its upper surface being everywhere at the same temperature as the water in contact with it, while its lower surface is, by hypothesis, at a temperature 1° higher.] If, for instance, the plate be of Calton Hill trap-rock, the water must, according to the result we have found, flow at the rate of 141·1 times its length in a year, or of ·3863 of its length in twenty-four hours, to be raised just 1° in temperature in flowing over it. Thus water, one French foot deep, flowing over a plane bed of such rock at the rate of ·3863 of a mile in twenty-four hours, will, in flowing one mile, have its temperature raised 1° by heat conducted through the plate. The rates required to fulfil similar conditions for the sand of the Experimental Gardens and the sandstone of Craigleith Quarry are similarly found to be ·2435 of the length and ·9929 of the length, in twenty-four hours.

XVIII.—*On a Method of Reducing Observations of Underground Temperature, with its Application to the Monthly Mean Temperatures of Underground Thermometers, at the Royal Edinburgh Observatory.* By JOSEPH D. EVERETT, M.A., Professor of Mathematics, &c., in King's College, Windsor, N.S., and late Secretary to the Meteorological Society of Scotland.

(Read 30th April 1860.)

A few years since I was engaged in the performance of some calculations under the direction of Professor W. THOMSON of Glasgow, having reference to the observations of underground temperature made at the Royal Edinburgh Observatory. In this paper I propose to describe a modification of Professor THOMSON'S method, which, while retaining a sufficient degree of accuracy, will be simple enough for general adoption. The objects proposed are—

1*st*, To express the variations of temperature at a given depth in terms of the time of year.

2*d*, To deduce the conducting power of the soil.

In the calculations performed for Professor THOMSON, the temperatures at 32 equal intervals in each year were required as the basis of calculations; and as the observations had been made only once a-week, it was requisite to interpolate, either by graphical projection (which was the method employed) or in some other way.

A Report of the Royal Edinburgh Observatory having recently passed through my hands, containing the mean temperature of each of the underground thermometers for each month of each year during a period of seventeen years, I have adapted Professor THOMSON'S method to a computation from 12 (instead of 32) points in the year, and have applied the method thus modified to the means on the seventeen years' observations. The present paper embodies the results, which will be found to agree pretty closely with those obtained by the more elaborate method. The monthly mean temperatures printed in the Observatory Report, on the averages of which, for the seventeen years, the following results are based, are simply the arithmetical means of the weekly readings taken in each calendar month.

For the sake of making the paper intelligible, it will be necessary to premise a few principles which are common to both methods.

The form of expression to which the temperature of each thermometer is to be reduced, is

$$v = A_0 + P_1 \sin\left(2\pi\frac{t}{T} + E_1\right) + P_2 \sin\left(4\pi\frac{t}{T} + E_2\right) + \&c. \quad . \quad . \quad (1.)$$

the general term being $P_n \sin\left(2n\pi\frac{t}{T} + E_n\right)$

Where v is the temperature at the line t from the epoch of reckoning, T is the periodic time (a year), π is the ratio of the circumference of a circle to the diameter, and A_0, P_1, P_2, E_1, E_2, &c. are constants, whose value must be found from the temperatures observed.

It is evident from the form of the expression that A_0 is the mean temperature of the whole year, and that the maximum and minimum values of any subsequent term $P_n \sin\left(2n\pi\frac{t}{T} + E_n\right)$ are $+P_n$ and $-P_n$ respectively. As the range of value through which any term passes depends only on the coefficient P_n, this coefficient is styled the *amplitude* of the term, being in fact equal to half the range.

The epochs of maxima and minima will be very different for different terms. The term involving P_1 has one maximum and one minimum in the year. The term involving P_2 has two maxima and two minima, and generally the term in P_n has n maxima and n minima in the year, its values going through their entire cycle in the $\frac{1}{n}$th part of a year. The term in P_1 is therefore called the annual term, and the term in P_2 the half-yearly term.

The maximum and minimum values of a term will occur earlier or later in the year, according to the value of the constant E_n, any diminution in the value of E_n being the same thing as a retardation of the maxima and minima. Such retardation is called *retardation of phase.* It is the diminution of amplitude and retardation of phase between the terms for thermometers at different depths, that afford the means of deducing the conducting power of the soil.

In order to find from the observed temperatures the values of the constants in expression (1), we must make use of the equivalent expression—

$$v = A_0 + \left(A_1 \cos 2\pi\frac{t}{T} + B_1 \sin 2\pi\frac{t}{T}\right) + \left(A_2 \cos 4\pi\frac{t}{T} + B_2 \sin 4\pi\frac{t}{T}\right) + \&c.$$

the general term being $\left(A_n \cos 2n\pi\frac{t}{T} + B_n \sin 2n\pi\frac{t}{T}\right) \quad . \quad . \quad (2.);$

and then by applying the equations of transformation

$$\sqrt{A_n^2 + B_n^2} = P_n \ , \ \frac{A_n}{B_n} = \tan E_n \quad . \quad . \quad . \quad . \quad (3.)$$

we shall obtain the values of the constants in expression (1).

In the calculations performed for Professor THOMSON, the expressions were carried as far as the terms depending on A_4 and B_4. I have carried them only as

far as A_2 and B_2, the convergence of the terms being so rapid that a good approximation to the value of the whole series is thus obtained. For deducing the conducting power of the soil even this is more than is required, the values of any single term (except A_0) for the different thermometers being all that theory requires, and the values of A_1 and B_1, inasmuch as they admit of more accurate determination than the coefficients of following terms, can be most advantageously used for making this deduction.

The process for finding the values of A_0, A_1, B_1, &c., is different according to the number of points in the year that are taken. To find analytically the process for 12 points in the year, let

v_0 denote the temperature at the epoch of commencement;

v_1 " " $\frac{1}{12}$ of the year later;

v_2 " " $\frac{2}{12}$ " "

&c. &c.,

and let the sines of 0°, 30°, 60°, and 90°, be denoted by S_0, S_1, S_2, S_3 respectively; we have then the following values of v for the 12 points in the year:—

I.

$$
\begin{aligned}
v_0 &= A_0 + A_1 S_3 + A_2 S_3 + B_1 S_0 + B_2 S_0 \\
v_1 &= A_0 + A_1 S_2 + A_2 S_1 + B_1 S_1 + B_2 S_2 \\
v_2 &= A_0 + A_1 S_1 - A_2 S_1 + B_1 S_2 + B_2 S_2 \\
v_3 &= A_0 + A_1 S_0 - A_2 S_3 + B_1 S_3 - B_2 S_0 \\
v_4 &= A_0 - A_1 S_1 - A_2 S_1 + B_1 S_2 - B_2 S_2 \\
v_5 &= A_0 - A_1 S_2 + A_2 S_1 + B_1 S_1 - B_2 S_2
\end{aligned}
$$

II.

$$
\begin{aligned}
v_6 &= A_0 - A_1 S_3 + A_2 S_3 - B_1 S_0 + B_2 S_0 \\
v_7 &= A_0 - A_1 S_2 + A_2 S_1 - B_1 S_1 + B_2 S_2 \\
v_8 &= A_0 - A_1 S_1 - A_2 S_1 - B_1 S_2 + B_2 S_2 \\
v_9 &= A_0 - A_1 S_0 - A_2 S_3 - B_1 S_3 + B_2 S_0 \\
v_{10} &= A_0 + A_1 S_1 - A_2 S_1 - B_1 S_2 - B_2 S_2 \\
v_{11} &= A_0 + A_1 S_2 + A_2 S_1 - B_1 S_1 - B_2 S_2
\end{aligned}
$$

Subtracting the quantities in column II. from those in column I. we find

III.

$$
\begin{aligned}
v_0 - v_6 &= 2\,A_1 S_3 + 2\,B_1 S_0 \\
v_1 - v_7 &= 2\,A_1 S_2 + 2\,B_1 S_1 \\
v_2 - v_8 &= 2\,A_1 S_1 + 2\,B_1 S_2 \\
v_3 - v_9 &= -2\,A_1 S_0 + 2\,B_1 S_3
\end{aligned}
$$

IV.

$$
\begin{aligned}
v_5 - v_{11} &= -2\,A_1 S_2 + 2\,B_1 S_1 \\
v_4 - v_{10} &= -2\,A_1 S_1 + 2\,B_1 S_2
\end{aligned}
$$

Subtracting the quantities in column IV. from those opposite to them respectively in column III. (remembering that $S_0 = 0$, and $S_3 = 1$), we obtain the remainders—

$$2\,A_1 \qquad 4\,A_1 S_2 \qquad 4\,A_1 S_1 \qquad 2\,B_1$$

If these be multiplied respectively by the factors,

$$1 \qquad S_2 \qquad S_1 \qquad 0$$

the products are

$$2\,A_1 \qquad 4\,A_1 (S_2)^2 \qquad 4\,A_1 (S_1)^2 \qquad 0$$

and the sum of these four products (since $(S_1)^2+(S_2)^2=1$) is $6\ A_1$. Hence the value of A_1 can be found.

Again, adding the quantities which stand opposite to each other in columns III. and IV. we have the sums

$$2\ A_1 \qquad 4\ B_1\ S_1 \qquad 4\ B_1\ S_2 \qquad 2\ B_1\ ;$$

and if we multiply these respectively by the factors,

$$0 \qquad S_1 \qquad S_2 \qquad 1$$

we obtain the products,

$$0 \qquad 4\ B_1\ (S_1)^2 \qquad 4\ B_1\ (S_2)^2 \qquad 2\ B_1$$

The sum of these products is $6\ B_1$; hence B_1 can be found.

Adding the terms opposite each other in columns I. and II. we find

V.	VI.
$v_0+v_6=2\ A_0+2\ A_2\ S_3+2\ B_2\ S_0$	$v_3+v_9=2\ A_0-2\ A_2\ S_3-2\ B_2\ S_0$
$v_1+v_7=2\ A_0+2\ A_2\ S_1+2\ B_2\ S_2$	$v_4+v_{10}=2\ A_0-2\ A_2\ S_1-2\ B_2\ S_2$
$v_2+v_8=2\ A_0-2\ A_2\ S_1+2\ B_2\ S_2$	$v_5+v_{11}=2\ A_0+2\ A_2\ S_1-2\ B_2\ S_2$

The sum of all the terms in V. and VI. is $12\ A_0$, which is in fact the sum of the 12 values of v.

Subtracting the quantities in VI. from those opposite to them in V., we have the remainders,—

$$4\ A_2 \qquad 4\ A_2\ S_1+4\ B_2\ S_2 \qquad -4\ A_2\ S_1+4\ B_2\ S_2.$$

Multiply these remainders respectively by

$$1 \qquad S_1 \qquad -S_1$$

and omitting the two terms $4\ B_2\ S_1\ S_2$ and $-4\ B_2\ S_1\ S_2$, which destroy one another, we have the products—

$$4\ A_2 \qquad 4\ A_2\ (S_1)^2 \qquad 4\ A_2\ (S_1)^2$$

whose sum (since $S_1=\frac{1}{2}$) is $6\ A_2$. Hence A_2 can be found.

Again, if the above remainders be multiplied respectively by

$$0 \qquad S_2 \qquad S_2$$

the products (omitting terms which destroy each other) are

$$0 \qquad 4\ B_2\ (S_2)^2 \qquad 4\ B_2\ (S_2)^2$$

and since $S_2=\frac{\sqrt{3}}{2}$, the sum of these products is $6\ B_2$. Hence B_2 can be found.

The application of the process above indicated to the determination of A_1 B_1 A_2 B_2 for the 3 feet thermometer is subjoined.

I. Temperatures of first 6 months.	II. Temperatures of last 6 months.	III. I. – II.	IV. Last two Nos. in III. reversed.	III. – IV.	Multipliers.	Products.	III. + IV.	Multipliers.	Products.
40·57	52·70	–12·13		–12·13	1	–12·13	–12·13	0	– 0·00
39·64	53·82	–14·18	+7·24	–21·42	S_2	–18·55	– 6·94	S_1	– 3·47
40·31	52·75	–12·44	+0·35	–12·79	S_1	– 6·39	–1209	S_2	–10·47
42·45	49·15	– 6·70		– 6·70	0	·00	– 6·70	1	– 6·70
45·87	45·52	+ 0·35			6)	–37·07		6)	–20·64
49·86	42·62	+ 7·24			A_1=	– 6·18		B_1=	– 3·44

V. First Half of (I. + II.)	VI. Last Half of (I. + II.)	V. – VI.	Multipliers.	Products.	V. – VI. again.	Multipliers.	Products.
93·27	91·60	+1·67	1	+1·67	1·67	0	·00
93·46	91·39	+2·07	S_1	+1·035	+2·07	S_2	+2·295
93·06	92·48	+0·58	$-S_1$	–0·290	+0·58	S_2	
			6)	+2·415		6)	+2·295
			A_2=	+ ·4025		B_2=	+ ·3825

A_0 = mean of all the numbers in I. and II. = 46·27.

There are in all four thermometers, their bulbs being sunk to depths of 3, 6, 12, and 24 French feet respectively below the surface of the ground. The means of their readings, in degrees Fahrenheit, for each calendar month, on the average of the seventeen years 1838–1854, are as under:—

Depth of Thermometer.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
3 feet	40·57	39·64	40·31	42·45	45·87	49·86	52·70	53·82	52·75	49·15	45·52	42·62
6 feet	43·59	42·35	42·00	42·79	44·65	47·23	49·71	51·31	51·54	50·11	47·81	45·48
12 feet	46·84	45·82	45·06	44·68	44·88	45·63	46·84	48·07	48·96	49·27	49·02	47·94
24 feet	47·77	47·63	47·39	47·08	46·79	46·59	46·55	46·69	46·97	47·31	47·61	47·79

The values of A_0, A_1, B_1, A_2, B_2, obtained in the manner above indicated, are—

	A_0	A_1	B_1	A_2	B_2
For the 3 feet thermometer,	46·27	−6·18	−3·44	+·4025	+·3825
... 6 feet ...	46·55	−3·10	−3·65	+·120	+·293
... 12 feet ...	46·92	+0·03	−2·31	−·0833	+·0635
... 24 feet ...	47·18	+0·615	−0·118	−·0167	−·0144

And the values of P_1, P_2, E_1, E_2, obtained from these by the formulæ of transformation (3), are—

	P_1	P_2	E_1	E_2
For the 3 feet thermometer,	7·07	·56	240° 54′	46° 27½′
... 6 feet ...	4·79	·32	220° 20′	22° 16′
... 12 feet ...	2·31	·10	179° 15′	− 52° 41′
... 24 feet ...	·63	·02	100° 52′	−130° 46′

With the view of testing how nearly the formulæ give the true temperature of each month, I have calculated the temperature of each thermometer for each month both by formula (1) and formula (2), the results in the two cases being identical; and the following table exhibits their differences from the actual temperatures. The numbers in the first line are the actual temperatures; those in the second line are obtained by putting t successively equal to 0, $\frac{1}{12}$ T, $\frac{2}{12}$ T, &c. in expressions (1) and (2); and those in the third line are the corrections necessary for reducing the calculated to the actual temperatures. For the sake of exhibiting the variations of temperature more clearly, the temperatures have in each case been diminished by the mean of the year, so that temperatures below the mean bear the negative sign.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
3 feet Ther.												
Actual,	−5·70	−6·63	−5·96	−3·82	−0·40	+3·59	+6·43	+7·55	+6·48	+2·88	−0·75	−3·65
By formula,	−5·78	−6·54	−5·94	−3·84	−0·42	+3·50	+6·58	+7·60	+6·20	+3·04	−0·64	−3·76
Difference,	+ ·08	− ·09	− ·02	+ ·02	+ ·02	+ ·09	− ·15	− ·05	+ ·28	− ·16	− ·11	+ ·11
6 feet Ther.												
Actual,	−2·96	−4·20	−4·55	−3·76	−1·90	+0·68	+3·16	+4·76	+4·99	+3·56	+1·26	−1·07
By formula,	−2·98	−4·20	−4·52	−3·77	−1·93	+0·67	+3·22	+4·82	+4·91	+3·53	+1·30	−1·05
Difference,	+ ·02	·00	− ·03	+ ·01	+ ·03	+ ·01	− ·06	− ·06	+ ·08	+ ·03	− ·04	− ·02
12 feet Ther.												
Actual,	−0·08	−1·10	−1·86	−2·24	−2·04	−1·29	−0·08	+1·15	+2·04	+2·35	+2·10	+1·02
By formula,	−0·05	−1·12	−1·89	−2·23	−2·03	−1·28	−0·11	+1·14	+2·08	+2·39	+2·00	+1·08
Difference,	− ·03	+ ·02	+ ·03	− ·01	− ·01	− ·01	+ ·03	+ ·01	− ·04	− ·04	+ ·10	− ·06
24 feet Ther.												
Actual,	+ ·59	+ ·45	+ ·21	− ·10	− ·39	− ·59	− ·63	− ·49	− ·21	+ ·13	+ ·43	+ ·61
By formula,	+ ·60	+ ·45	+ ·20	− ·10	− ·39	− ·59	− ·63	− ·49	− ·21	+ ·13	+ ·43	+ ·60
Difference,	− ·01	·00	+ ·01	·00	·00	·00	·00	·00	·00	·00	·00	+ ·01

If we had neglected the term involving P_2 (the half-yearly term), and taken only the term involving P_1 (the annual term), we should have obtained the results entered in the first line of the following table. The numbers in the second line are the corrections necessary for reducing these results to the actual temperatures.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Results,	−6·18	−7·07	−6·07	−3·44	+0·11	+3·63	+6·18	+7·07	+6·07	+3·44	−0·11	−3·63
Corrections,	+ ·48	+ ·44	+ ·11	− ·38	− ·51	− ·04	·25	+ ·48	+ ·41	− ·56	− ·64	− ·02
Results,	−3·10	−4·51	−4·71	−3·65	−1·61	+0·86	+3·10	+4·51	+4·71	+3·65	+1·61	−0·86
Corrections,	+ ·14	+ ·31	+ ·16	− ·11	− ·29	− ·18	+ ·06	+ ·25	+ ·28	− ·09	− ·35	− ·21
Results,	+0·03	−1·13	−1·98	−2·31	−2·02	−1·18	−0·03	+1·13	+1·99	+2·31	+2·02	+1·18
Corrections,	− ·11	+ ·03	+ ·12	+ ·07	− ·02	− ·11	− ·05	+ ·02	+ ·05	+ ·04	+ ·08	− ·16
Results,	+ ·62	+ ·47	+ ·20	− ·12	− ·41	− ·59	− ·62	− ·47	− ·21	+ ·12	+ ·41	+ ·59
Corrections,	− ·03	− ·02	+ ·01	+ ·02	+ ·02	·00	− ·01	− ·02	·00	+ ·01	+ ·02	+ ·02

The processes hitherto described are applicable not only to underground temperatures, but also to open-air temperatures, and, in fact, to any element that varies in a regular manner.

It remains to show how the results which we have obtained can be applied for determining the conductivity of the soil. The mode of procedure will be exactly the same as that adopted in the calculations for Professor THOMSON.

The conducting power of the soil may be inferred either from the diminution in the values of P_1 and P_2 as we descend in the soil, or from the diminution of E_1 and E_2. In other words, it may be inferred either from diminution of amplitude, or from retardation of phase.

Let x denote the difference in depth of any two of the thermometers; let $\Delta . E_n$ denote the retardation of phase, or the excess of the value of E_n, for the upper of the two thermometers above its value for the lower, E_n being expressed not in degrees and minutes, but in circular measure; and let $\Delta . \log_e P_n$ denote the diminution of the Napierian logarithm of the amplitude, or the excess of $\log_e P_n$ for the upper thermometer above $\log_e P_n$ for the lower; the ratio of k, the conductivity of the soil, to c, the capacity of the soil, for heat, may then be determined by either of the equations

$$\frac{\Delta . E_n}{x}=\sqrt{\frac{n\pi c}{Tk}} \qquad \frac{\Delta . \log_e P_n}{x}=\sqrt{\frac{n\pi c}{Tk}} \quad . \quad . \quad . \quad . \quad (4)$$

The manner in which these equations are deduced from the differential equation for the flow of heat through the soil,

$$\frac{dv}{dt}=\frac{k}{c} \cdot \frac{d^2v}{dx^2},$$

will be stated in a note at the end of this paper. At present we proceed to apply the equations to the numerical results above obtained.

The values of E_1 and E_2 in circular measure, and of $\log_e P_1$ and $\log_e P_2$, are as under:—

	$\log_e P_1$	$\log_e P_2$	E_1 in circular measure.	E_2 in circular measure.
3 feet thermometer	1·95	− ·59	4·20	+ ·81
6 feet „	1·56	−1·15	3·85	+ ·39
12 feet „	·84	−2·25	3·15	− ·92
24 feet „	− ·47	−3·81	1·76	−2·28

By comparing the thermometers two and two in every possible combination, the following results are obtained:—

For the Annual Term.

Thermometers compared.	$\Delta\ E_1$	z	$\sqrt{\frac{\pi c}{Tk}}$	$\Delta\ \log_e P_1$	z	$\sqrt{\frac{\pi c}{Tk}}$
3 feet and 6 feet.	·35	3	·117	.39	3	·130
3 feet and 12 feet.	1·05	9	·117	1·11	9	·123
3 feet and 24 feet.	2·44	21	·116	2·42	21	·115
6 feet and 12 feet.	·70	6	·117	·72	6	·120
6 feet and 24 feet.	2·09	18	·116	2·03	18	·113
12 feet and 24 feet.	1·39	12	·116	1·31	12	·109
Means, ...			·1165	. . .		·1183

For the Half-yearly Term.

Thermometers compared.	$\Delta\ E_2$	z	$\sqrt{\frac{2\pi c}{Tk}}$	$\Delta\ \log_e P_2$	z	$\sqrt{\frac{2\pi c}{Tk}}$
3 feet and 6 feet.	·42	3	·140	·56	3	·187
3 feet and 12 feet.	1·73	9	·192	1·66	9	·184
3 feet and 24 feet.	3·09	21	·147	3·22	21	·153
6 feet and 12 feet.	1·31	6	·218	1·10	6	·183
6 feet and 24 feet.	2·67	18	·148	2·66	18	·148
12 feet and 24 feet.	1·36	12	·113	1·56	12	·130
Means, ...			·160	. . .		·164
Quotients by $\sqrt{2}$, . . .			·113	. . .		·116

The results deduced from the annual term agree the best among themselves, and are the most reliable; the coefficients P_2 of the half-yearly term being very small, and varying considerably from year to year. Notwithstanding, the mean values ·113, ·116 of $\sqrt{\frac{\pi c}{Tk}}$, deduced from the half-yearly term, agree very well with the values ·1165, ·1183 from the annual term. Professor Thomson's results from the temperatures of the thirteen years 1842–1854 were:—

	By Phase.	By Amplitude.
For the annual term, . . .	·1156	·1160
For the half-yearly term, . .	·08861	·11133

—these numbers being the values of the function $\sqrt{\frac{\pi c}{Tk}}$ obtained from the coeffi-

cients in the same manner as above. The agreement as regards the annual term is very remarkable, extending, as it does, both in the determination from phase and in that from amplitude to the fourth decimal place.

Note on the Equations

$$\frac{\Delta \, . \, \mathrm{E}}{x} = \sqrt{\frac{n\pi c}{\mathrm{T}k}} = \frac{\Delta \, . \, \log_e \mathrm{P}_n}{x}.$$

The differential equation for the conduction of heat through the soil, the surface being supposed horizontal and the soil uniform, is

$$\frac{dv}{dt} = \frac{k}{c} \cdot \frac{d^2v}{dx^2}.$$

This equation is satisfied if we assume

$$v = \mathrm{P}e^{-x\sqrt{\frac{n\pi c}{\mathrm{T}k}}} \sin \left(2n\pi\frac{t}{\mathrm{T}} + \mathrm{E}_n - x\sqrt{\frac{n\pi c}{\mathrm{T}k}}\right)$$

—e being the base of Napierian logarithms, and P any constant.

To show that this integral satisfies the differential equation, put

$$\sqrt{\frac{n\pi c}{\mathrm{T}k}} = \alpha, \qquad \frac{2n\pi t}{\mathrm{T}} + \mathrm{E} - \beta.$$

The equation then becomes

$$v = \mathrm{P}e^{-\alpha x} \sin (\beta - \alpha x).$$

Whence

$$\frac{dv}{dt} = \frac{d\beta}{dt} \, . \, \mathrm{P}e^{-\alpha x} \cos (\beta - \alpha x) = \frac{2n\pi}{\mathrm{T}} \, . \, \mathrm{P}e^{-\alpha x} \cos (\beta - \alpha x)$$

$$\frac{dv}{dx} = -\mathrm{P}\alpha e^{-\alpha x} \left\{ \sin (\beta - \alpha x) + \cos (\beta - \alpha x) \right\}$$

$$\frac{d^2v}{dx^2} = \mathrm{P}\alpha^2 e^{-\alpha x} \left\{ \sin (\beta - \alpha x) + \cos (\beta - \alpha x) + \cos (\beta - \alpha x) - \sin (\beta - \alpha x) \right\}$$

$$= 2 \, \mathrm{P}\alpha^2 e^{-\alpha x} \cos (\beta - \alpha x).$$

Hence

$$\frac{dv}{dt} = \frac{n\pi}{\mathrm{T}} \cdot \frac{1}{\alpha^2} \cdot \frac{d^2v}{dx^2}; \text{ but } \frac{1}{\alpha^2} = \frac{\mathrm{T}k}{n\pi c}.$$

Whence

$$\frac{dv}{dt} = \frac{k}{c} \cdot \frac{d^2v}{dx^2}, \text{ or the differential equation is satisfied.}$$

It will be equally satisfied if, instead of a single term, we have a series of terms of the same form as that above assigned to v, and if we likewise prefix a constant A_0. Hence we have the general equation

$$v = A_0 + P_1 e^{-x\sqrt{\frac{\pi c}{Tk}}} \sin\left(2\pi\frac{t}{T} + E_1 - x\sqrt{\frac{\pi c}{Tk}}\right) + P_2 e^{-x\sqrt{\frac{2\pi c}{Tk}}} \sin\left(4\pi\frac{t}{T} E_2 - x\sqrt{\frac{2\pi c}{Tk}}\right) + \&c.$$

the general term being

$$P_n e^{-x\sqrt{\frac{n\pi}{Tk}}} \sin\left(2n\pi\frac{t}{T} + E_n - x\sqrt{\frac{n\pi c}{Tk}}\right).$$

In this equation x denotes the distance below any assumed horizontal plane. Let the plane pass through the bulb of one of the thermometers; then the general term will become for this thermometer

$$P^n \sin\left(2n\pi\frac{t}{T} + E^n\right);$$

while for a thermometer lower by x feet it is

$$P\, e^{-x\sqrt{\frac{n\pi}{Tk}}} \sin\left(2n\pi\frac{t}{T} + E_n - x\sqrt{\frac{n\pi c}{Tk}}\right).$$

Hence it appears that in descending through x feet the amplitude P_n is diminished in the ratio of $e^{-x\sqrt{\frac{n\pi c}{Tk}}}$ to 1, while the quantity E_n is diminished by the amount $x\sqrt{\frac{n\pi c}{Tk}}$. Whence the equations

$$\frac{\Delta \,.\, \log_e P}{x} = \frac{\Delta\, E}{x} = \sqrt{\frac{n\pi c}{Tk}}.$$

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